THE CONSTRUCTION AND DURATION OF THE PERMANENT WAY OF RAILWAYS IN EUROPE,

AND

THE MODIFICATIONS MOST SUITABLE TO EGYPT, INDIA, &c.

BY

WILLIAM BRIDGES ADAMS.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPER.

EDITED BY

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SECRETARY.

BY PERMISSION OF THE COUNCIL.

EXCERPT MINUTES OF PROCEEDINGS
OF THE
INSTITUTION OF CIVIL ENGINEERS,
Vol. XI.
SESSION 1851–52.

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LONDON: PRINTED BY WILLIAM CLOWES AND SONS,
STAMFORD STREET AND CHARING CROSS.
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INSTITUTION
OF
CIVIL ENGINEERS.

February 10th, 1852.

JAMES MEADOWS RENDEL, President, in the Chair.

No. 866. "The Construction and Duration of the Permanent Way of Railways in Europe, and the modifications most suitable to Egypt, India, &c." By WILLIAM BRIDGES ADAMS.[1]

In examining the "Permanent Way" of various kinds, used up to the present period, it is necessary first to settle the exact meaning of the term. In its simple sense, it would imply a way of great durability; but that it does not satisfactorily fulfil this condition, may be assumed from the numerous changes and attempts at improvement it is constantly undergoing.

It must therefore be understood, that the term "permanent way" means some kind of way left by the contractor, when he has removed his temporary way, and which may be of greater, or less, durability, or permanence, according to its structure, but which must, in most cases, be governed by the quality of the material that can be most easily procured. Where timber is plentiful, it is largely used for the substructure; if it is scarce, stone is substituted; and if the capital is restricted, the iron is pinched too closely, as on the early railways, in the United States. Whilst the ballast also varies according to locality, from broken stone, and burnt clay, to sand and gravel.

The principal requirements of "permanent way" are; that it be well drained, and especially in contiguity to the substructure. That the weight and damaging power of the engines and rolling stock, should be considered as the datum for calculation. That the strength, hardness, and tenacity of the rails, and the immobility of the substructure, should be adapted for the hardest work to which the railway is to be subjected. That the substructure should have an amount of bearing surface, proportioned to the load to be borne, and the nature of the soil, or ballast; and a sufficiently firm hold

[1] The discussion on this paper extended over a portion of three evenings, but an abstract of the whole is given consecutively.

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in the ground, to prevent looseness, or lateral movement, from the side lurches of the engines, or trains. That the rails should possess so much vertical and lateral stiffness, either in themselves, or by their fastenings, as to prevent all deflection, and have sufficient hardness of surface not to laminate, or to disintegrate, beneath the rolling loads; and have sufficient breadth, or tread-surface, to diminish the effect of the crushing power of the wheels. They should be as smooth as possible on the running surface, to prevent concussion; and be laid at the proper angle, and the curves regularly bent, so as to insure the accurate tread of the wheels: whilst the joints should be so made, that the rails may, practically, become continuous bars, yet with freedom to expand and contract without being too loose. And with all this, there should be interposed, between the rails and the solid ground, some medium, sufficiently elastic to absorb the effect of the blows of the wheels, without being crushed, or forced down into the ballast, and yet stiff enough to keep the upper surface of the rails in a uniform plane.

If these conditions are fulfilled the railway will be a "permanent way" in the full sense of the term.

The ballast may be considered the foundation of the railway; and the depth of it must vary with the structure. If sleepers are used in the ordinary manner, they should be sunk into the ballast, and yet have a sufficient quantity below, to prevent them from gradually sinking. Therefore, the thicker and more efficient the sleeper, the greater must be the depth of the ballast; and this makes the choice of the sleeper an important consideration; which again, is regulated by the kind of rail intended to be used.

The earliest, cheapest, or rather lowest priced and worst form, of wrought-iron rails, is the flat tire-bar rail, spiked down on a longitudinal balk. This was adopted on most of the American railways at the outset, but is now abandoned, on account of the enormous wear and tear, and the great danger to passengers, as the ends curled up, and occasionally killed a passenger, through the bottom of the carriage.

A variation of this kind of way, with the bars edgewise, has been for many years in use in quarries and other places where only a slow motion of the trams is required.

The next in order is the single T fish-bellied rail, ranging from 28 lbs. to 35 lbs. per yard. It was originally patented by Mr. Birkinshaw, in the year 1820, and was first employed to any considerable extent, by Mr. G. Stephenson, on the Liverpool and Manchester Railway (1829-30); but is now no longer manufactured. This rail

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is a remarkable instance of correct reasoning from unproved data, for though all chair-rails are practically girders, the chairs being the supporting piers, yet in a rail 15 feet long, when the chairs yielded, that reduced portion of the rail which was supported by them, would also yield and bend; so that instead of making the rail a succession of fish-bellies, it ought rather to have been one single curved line at the bottom, as in the case of the cast-iron fish-bellied rail.

The next is the single T parallel rail used with a cast-iron chair: this form, which was first extensively used by Mr. Vignoles, about the year 1833, is a valuable rail, under some special applications, hereafter to be noticed.

The next is the double I parallel rail, generally used with chairs: this is a convenient, as well as a very strong mechanical form, and is well adapted for traffic. This double table-rail was first practically adopted on the Grand Junction Railway, by Mr. Locke, M.P., V.P., under whose directions the precise form was carried out by Mr. C. Manby (now Secretary of the Institution of Civil Engineers), to whom the order was given for manufacturing the first quantity, at the Ebbw Vale Ironworks, South Wales, early in the year 1835, when a very elaborate series of investigations was made by Mr. Locke, on the various forms of rails, and chairs, the material for, and the distances between the sleepers, &c. The rail was 4½ inches deep, with a flat bearing-surface of 2½ inches wide on the top and bottom tables, which were precisely similar, and the weight was about 62 lbs. per yard. The chairs were of cast-iron, and were originally intended to have in each a metal filling-in piece, with a round oak trenail, or plug, between it and the face of the jaw of the chair, in order to force it against the web of the rail: this plan was, however, after a very short trial, abandoned, and solid plugs of oak were substituted for the iron filling-in piece and oak trenail. These oak plugs, or keys, were compressed into iron moulds, under hydraulic presses, by Mr. Beattie, at the Crown-street works, Liverpool, where, under Mr. Locke's directions, the same process had been in operation for two years previously, and the compressed plugs were first tried on the Liverpool and Manchester Railway.

The foot-rail, a single (reversed) ⊥ section, with a broad foot, or base, to stand on longitudinal timbers, or on cross sleepers, to which it was bolted down, through holes in the foot, was generally known as the 'Stephenson and Vignoles rail.' It is now commonly used by contractors for a temporary way, with transverse sleepers, to which it is attached by dogs, or spikes, and it was, at one period, extensively used in the United States for permanent way, but

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being sometimes insufficiently fastened down by spikes, it not unfrequently caused accidents.

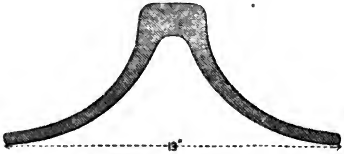
Then comes the well-known bridge-rail, first used by Mr. Brunel on the Great Western Railway in 1838, and subsequently, on many other lines.

The rail manufactured by Sir John Guest, for Mr. Stevens, C.E. (U. S. America), is generically a foot-rail, but as it is 7 inches in height, with a foot only $4\frac{3}{4}$ inches in width, and the vertical web only $\frac{1}{2}$ inch in thickness, it is obvious that it must be supported laterally. Probably this is accomplished by bolting it between two longitudinal timber balks, into which the foot is grooved; but the Author has not been able to gain information respecting its real mode of application.

Split rails, or rails rolled in two pieces, both in the form of the half of a double **I**, and also as a foot-rail, with a vertical joint between them, and put together so as to "break joint," are extensively used in America, being manufactured under a patent in England. The object of this form of rail is, in fact, to give a longitudinal scarf through the whole length, so as to prevent bad joints.

Barlow's "saddle-back rail" is the latest great innovation; it is used without sleepers; or, in the words of the patentee, "is a trough rail, bearing on the ballast, and riveted to bearers." (Fig. 1.)

Fig. 1.



Mr. W. H. Barlow's Saddle-back Rail.

Two general systems, known as the transverse and the longitudinal methods, have been adopted, for securing rails upon timber sleepers, and sometimes the two have been combined. But the desirability of adopting a material chemically durable, originally induced the use of stone blocks; and as these have been almost altogether abandoned, it will be well to inquire, why this has taken place, and if for sufficient reasons.

The blocks were usually about 2 feet square, by 1 foot in depth, containing 4 cubic feet of stone. They were of various qualities according to the localities, and were placed, sometimes rectangularly in line, with intervals between them, and at others diagonally, nearly touching at the corners, and forming a continuous foundation,

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or substructure; in some instances they were laid in ballast, and in others, only in the natural soil.

To insure solidity, which was the object then aimed at, the cast-iron chairs were fitted accurately to the stones, and fastened to them by a pair of iron spikes, each driven into an oak trenail, bedded about 6 inches deep, in a hole bored in the stone block. It was soon found, however, that the chairs worked loose and cut into the stones; and to remedy this, a layer of patent felt, an eighth of an inch in thickness, was placed between the chair and the stone, but the felt being crushed by the heavy weights, the chairs became looser than before. The most probable solution of the defect is this:—the stone blocks partially subsided, irregularly deflecting the rails, which were held down by the spikes, until the elasticity of the rail, in seeking to regain its form, gradually drew the fastenings, and then an incessant hammering ensued between the chair and the stone, on the passage of trains, gradually cutting into the surface of the stone a recess of the form of the chair. To pack the stone blocks, or to restore them to their proper position, at so great a depth, involved a costly operation. Moreover, the noise in travelling was a nuisance to the passengers, and the hardness was found to be very destructive to the rolling stock, and therefore the use of stone blocks was discontinued, and in many cases they were removed from existing lines, and were replaced by transverse timber-sleepers, previously only used in embankments of new construction, being in fact merely "contractors' way," but of larger scantling and materials.

Before the question was finally disposed of, an experiment was made on a portion of the Leeds and Manchester line, by levelling the solid rock, in which there could be no subsidence—and fastening the chairs to it, exactly as they had previously been attached to the stone blocks. The result it is said, was, to produce a road so hard and rigid, that it was impossible to continue the use of it, and this was considered to have definitely settled the question. If, however, instead of discarding the stone blocks, they had been used as foundations for supporting the timber sleepers, to which the rails could have been attached, it is probable that a much more really permanent way would have resulted.

The mechanical change that was effected, by the substitution of timber for stone, was comparative freedom from noise, which was undoubtedly an indication of a deflecting rail, rising and falling with the chairs on the blocks.

The same rail, transferred to the transverse sleepers, would also rise and fall, but without noise. And that they do deflect is proved by the oozing of watery mud from beneath the sleepers, in wet weather; by the quantity of dust, in dry weather, and by the necessity

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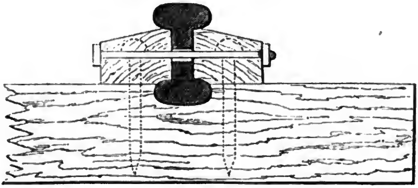
for continually packing the sleepers, which latter forms a large item of the cost of "maintenance of way."

Supposing the rails to be integrally strong enough to prevent deflection, when supported at their two ends, the seat of the rail in the chairs requires to be of sufficient area to prevent that indentation both of rail and chair, which may be occasionally seen to the depth of a quarter, or even three-eighths of an inch.

A simple method of avoiding the use of cast-iron chairs, and at the same time of firmly attaching the rails to the timber sleepers, would be to fasten, by transverse pins to both sides of the vertical web, two short bracket blocks of oak, resting upon the timber sleepers, to which they could be spiked, and supporting the top web of the rail; the bottom web resting upon and being grooved into the sleepers. The inner top of the bracket blocks would not touch the flanches of the wheels. The rails would thus be lower, the leverage would be less, the thickness of ballast would be reduced, the chairs entirely done away with, and considerable economy be effected. (Fig. 2.)

Fig. 2.



Rail without Chairs.

Again, it is essential, that the chair should have such a bearing surface on the timber-sleeper, and be so secured to it, that the side-lurch of the engine, and the springing of the sleeper across the width of the road, cannot disturb it.

The last consideration is, the bearing surface of the sleepers themselves on the ballast. There are generally under each parallel pair of rails, of 15 feet in length, six sleepers of about 9 feet in length, by 10 inches in width, and 5 inches in thickness.

The rail thus becomes a girder-bridge supported on piers, and when the rail deflects, the sleepers are forced into the ballast in detail.

To overcome this depression of the sleepers, either their number must be extended, if needful, till they touch each other, like the corduroy, or plank roads of America, or else the depth and strength of the rails must be increased, so as to prevent all deflection.

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In the longitudinal system of timber-sleepers, as used on the Great Western and other lines, with bridge-rails, having a continuous bearing on the timber, the bearing surface of the rails on the timber is about 6 inches in width, and that of the sleepers on the ballast is about 13 inches. The depth of the rail being about 3½ inches, and the depth of the timber 6 inches.

The quantity of timber used in the transverse system, with four intermediate sleepers to each length of rail, is rather less than 16 cubic feet, and on the longitudinal system it is rather more than 16 cubic feet; or with about the same quantity of timber, the bearing surface on the transverse plan will be about 12 inches in width; and on the longitudinal plan, about 13 inches, giving an advantage of 1 inch in width to each rail, or two inches to the pair of rails, in the longitudinal plan; but as in the latter plan, the sleepers are 1 inch deeper over the whole surface, the effective quantity of timber is nearly 3 cubic feet more. In comparing the expense of the two systems, the cost of the fastening of the rails may be assumed to be equal in both cases, and as the quantity of timber has been shown to be about equal, and the quality ought to be the same, the cost should be alike. For a long period the transverse timber system was considered the cheapest, but the reason was, that on many lines, the sleepers were very small, and of inferior quality, while in the case of the longitudinal system, it was essential always to have good timber. In addition to the increase of bearing surface in the longitudinal system, the broad base of the bridge-rail makes it much stiffer laterally, than the double I rail, and its smaller depth offers less opportunity of accident, from sudden lurches of the engine. But, on the other hand, the bridge-rail being only 3½ inches in depth, is liable to deflect under loads, by which the double I rail, 5 inches in depth, would not be affected.

Though the longitudinal timber tends to stiffen the bridge-rail vertically, the real effect depends entirely on the fastenings. The rail has two lateral flanches about 1¾ inch wide by ½ inch in thickness, through which holes are pierced at intervals of 3 feet.

In the earlier examples these rails were fastened down by screws; but as the rails and the timber deflected, a sliding movement took place between them, similar to that between the plates of a carriage-spring; the screws were loosened, drawn out, or broken, and the timber was crushed in detail. To remedy this, in some cases, the the timber was cross-boarded, with manifest advantage, and in most cases bolts with nuts passing through the rail-flanches and the timber, were substituted for the screw-bolts; subsequently, plates were introduced under the rail-ends, and also below the timber, and the

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bolts passed through all. But the author is not aware of any fastening yet being found quite effectual in preventing deflection, or the working movement between the rails, and the timbers, or the loosening of the bolt-heads.

On the old Croydon line, where the longitudinal system was used, with very light bridge-rails, it was not uncommon to find rails broken into two, or more lengths, by constant deflection, and they were repaired by placing a plate beneath the fractured ends.

With regard to the cost of repairs, the mere packing of the sleepers, under equal weights, should be less in the longitudinal system, because there is more bearing surface; but to set against that, the wood is more crushed than in the transverse system with chairs, and the access to the bolts is very troublesome, while the fastening of the double I rails in the chairs, by wooden keys, is very simple, though in the joint chair, it is insecure, and the rising of the ends is a common cause of accident. The author, therefore, in the year 1848, suggested a new variation, combining the use of the double I rail with the longitudinal sleeper, so as to avoid deflection and to obtain the continuous bearing. Dividing the half balk of timber, about 7 inches by 14 inches, into two parts, the double I rail was half-grooved into each, and bolts being passed through, below the rail, it was held as in a continuous wooden vice, embedded to the upper lip, the flanche of the engine-wheels being cleared by a shallow groove. Four lengths of this were laid down on the Eastern Counties' line, where it appeared to answer well, and is still in good order.

With respect to the durability of timber-sleepers there appears to be some difference of opinion, arising, probably, from the various descriptions of timber employed. There have been two principal systems employed, for rendering timber artificially durable. The one was by saturation with certain chemical solutions, or mineral salts, which act chiefly on the albumen, producing a kind of tanning effect, but by which the mechanical strength of the timber is stated to be impaired; moreover the salt being soluble in water, is apt to be washed out again. The other system, now very generally employed, is by 'creosoting,' or injecting coal-oil, under pressure, by which both mechanical toughness and chemical durability are produced.

Engineers have recently shown a disposition to resort to other materials, and it has been considered, whether it would not be possible to employ stone, which is chemically and mechanically the most durable material, and would afford a perfect foundation, provided the rails could be properly attached to the blocks.

If the thickness of these blocks was reduced from 12 inches to

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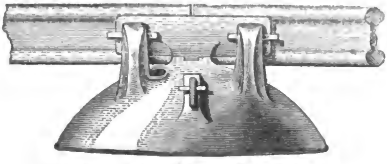
6 inches, the superficies remaining the same, and they were laid beneath each line of rails, nearly touching each other, and so as to support longitudinal sleepers, 8 inches by 6 inches deep, with bridge-rails, bolted down between every joint of the stones, through rails and timber to a small block below, a continuous bearing would be formed of chemically-durable sleepers, equal to 60 feet of surface beneath two rails, whilst a sufficient amount of elasticity would be given. At the same time it is probable, that no other ballast would be required, as the extended bearing surface would prevent displacement, and a true permanent way, when once settled and undisturbed by the rolling loads, would thus be formed.

Of course, the question of the cost of stone must depend chiefly on locality. In some districts it might be desirable to use cast-iron, or slate-flags, or the slag of the iron furnaces might be run into moulds. On this plan any kind of rail might be used; for instance, a deep foot-rail, with a half-foot angle-plate, bolted laterally to its break-joint, to save timber, or a girder-rail between timbers, or probably the double I rail bedded between two timbers, as before described.

The objections to the use of timber-sleepers, rendered very prominent by the inferior wood used in transverse structures, induced Mr. Reynolds, in 1836, to propose inverted troughs of cast-iron, lined with wood.[1]

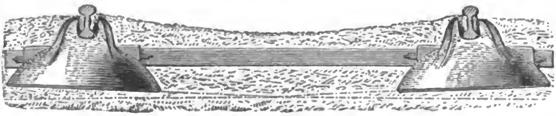
Subsequently, in 1846, Mr. Greaves, of Manchester, introduced a new metal sleeper, possessing several useful properties. (Figs. 3, 4, and 5.) This sleeper is a semi-spheroidal bowl of cast-iron,

Fig. 3.



Greaves' and Douglas' fish-joint Chair and Sleeper.

Fig. 4.



Greaves' surface-packed Sleepers, with Douglas' fish-joint Chairs.

[1] Vide Trans. Inst. C.E., vol. ii., 1838, page 73.

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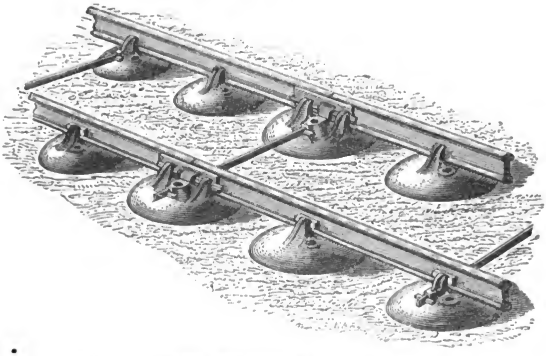
Fig. 5.



Greaves' surface-packed Sleepers.

having the chair, of any form, cast upon its apex, and is connected firmly with the opposite sleeper, at intervals, by a transverse bar, which preserves the gauge and retains the travelling table of the rail at the proper angle. The joint sleeper has Douglas' fish chair applied to it; this is a double-headed chair, with loose fishing plates of cast, or wrought iron, attached to the rails by split iron keys.

There are several advantages in this system; the form of the sleeper is strong,—it holds well in the ground;—the chair is not liable to be detached,—the whole bearing surface is directly beneath the load,—the ballast is always kept dry and elastic,—and there is an extremely ingenious contrivance for packing it through two holes, with a pointed rammer, from the surface, so that the sleeper and rail can be forced upwards, without disturbing the general bed of ballast, or they may be lowered by taking out a portion from the interior. The danger of admitting water, by opening the ground, is thus obviated, and in certain situations this is of great importance. The sleepers are in use on several lines in Great Britain, on the Continent, and in the Colonies, and Mr. Robert Stephenson, M.P., V.P., has adopted them for the Egyptian Railway.

The next kind of cast-iron sleeper was that introduced by Mr. Peter W. Barlow, M. Inst. C. E., in the year 1849, on the South Eastern Railway. (Figs. 6 and 7.) Each sleeper is in two pieces, and consists of a plate 3 feet long by 7 inches wide, with two half-chair heads cast upon it, except that for the joint-chair, which has

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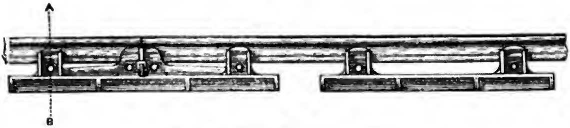
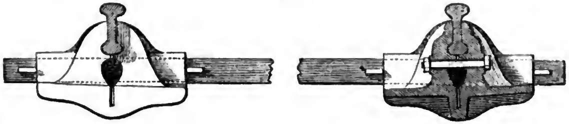
Fig. 6.



Mr. P. W. Barlow's Cast-iron Sleepers.

Fig. 7.



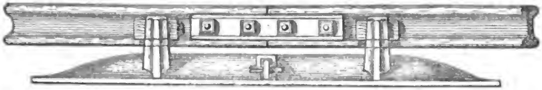
Elevation. Section.

three half-chair heads on it; these are made to grip the lower half of the rail tightly, by means of screw-bolts, passing through the chair-heads below the rails, and holding them as in a vice. The casting of these plates so as to fit the rail perfectly, and to preserve all the metal in a state of rest, is a work of some nicety.

Another cast-iron sleeper was brought forward by Mr. William H. Barlow, M. Inst. C. E.: it was very similar to the former, except that it was cast in one piece, the rails being fixed in the chairs by keys, in the usual manner, or by resting the rail on a wooden block, keyed in below it.[1]

[1] These sleepers are in use, and are much approved, on the Londonderry and Enniskillen and Londonderry and Coleraine Railways; and since the paper was read Mr. W. H. Barlow has adopted, with excellent results, on the Midland Railway, a form of cast-iron sleeper, combining the best properties of Mr. P. W. Barlow's sleeper, with the suspended fish-joint.—*Sec. Inst. C. E.* (Figs. 8 and 9.)

Fig. 8.



Mr. W. H. Barlow's Cast iron fish joint Sleeper, as used on the Midland Railway.

Fig. 9.

Elevation.

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In both these plans, it is evident, that the rail must be sufficiently stiff in itself, to prevent deflection, as the sleepers are not continuous. Mechanically considered, the latter plan appears the best, as the wood-keys can yield slightly and equalize the deflection of the rail, whereas, any bending of the rail, in the other plan, would be apt to break the sleepers.

The cast-iron sleeper introduced by Mr. Samuel, M. Inst. C. E., is a wedge-shaped trough, deep enough to take the total depth of the rail, with two inclined side wings, at the upper part, to bear on the ballast. The rail is grooved into two pieces of timber, which clip it at the bottom and the sides, and being forced into the trough, the wood is compressed. The troughs are, however, not continuous bearings, and therefore the rail must be strong enough not to deflect.

This is, mechanically, the best arrangement of the cast-iron sleepers hitherto examined; but as it is evident, that the retention of the rail in the timber cushion depends on the tenacity of the cast-iron trough, it must be made very strong, to prevent the wedging action from splitting it across the bottom. It is, however, a defective arrangement to make the bearing wings pitch downwards, as it induces unsteadiness; they should rather have been reversed, if not made horizontal.

The cast-iron sleeper, introduced by Mr. Hoby, like the sleeper of Mr. Samuel, is a trough, though of a different shape, the internal section being that of a prolonged chair, into which folding wedges are driven laterally, to secure the rail in its place. The side-bearing wings are pitched downwards, and the sleepers are not continuous. The rail fits in the bottom of the iron trough, and also against one side, and it will require very nice moulding and rolling to secure an accurate fit, but the elastic wood wedges will reduce the chance of fracture.

Another variety is an imported French sleeper, consisting of an ordinary chair, cast solid on a plate of 18 inches square, and merely resting on the surface of the ballast.

Another variety of sleeper is that of Major Cochrane. It is a flat cast-iron plate, with a pair of ribs upon it, forming a channel about two inches square, filled with timber, on which a flat-bottomed rail is held down by wedges, driven into projecting chair-heads, in the usual manner: it is evident, that if the rail deflects, the timber must be crushed, as it presents a very small bearing surface, and a rail with sufficient depth would possess a very unsteady base, unless the sleepers were cast in the form of a trough.

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Cast-iron may be used, efficiently, for railway sleepers, but the masses must be larger than have hitherto been applied, and the form must be continuous; or if detached, the sleepers should only serve as piers, or points of support, in which case the rail must be non-deflecting.

Having examined the different kinds of sleepers, with reference to the vertical and lateral support they afford to the rails, the next question is that of the various modes of attaching the rails to the sleepers, in order to prevent the jolting and unsteadiness usually experienced on ordinary railways.

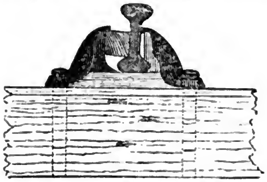
About the year 1832, or 1833, a reward of £100 sterling was offered by a railway company, for the best mode of securing rails to chairs. Many plans were sent in, but none were integrally adopted. It was said, that an amalgamation was effected between three of the competitors, and the reward was divided.

The fastening so rewarded was not successful, and it was soon found, that the wooden key was the only arrangement that did not rapidly get loose. Many of these, however, were too small; the rails were loosened laterally, and a creeping motion was induced by the action of the breaks on the wheels, not unfrequently causing accidents.

The mode of fastening the chairs to the sleepers, by means of iron spikes was insufficient. Rust got in between; the two irons were then rapidly worn away, and all became loose. This gave rise to the improved chairs of Messrs. Ransomes and May, hardened in chills to prevent the rails from crushing them, but not preventing them from crushing the rails, and with large-sized compressed trenails of oak, to attach them to the sleepers. (Figs. 10, 11, 12, 13, 14, 15, and 16.)[1]

Fig. 10.

Ransomes and May's Chairs and compressed Wedges and Trenails.



Elevation of Chair, showing the inclination of the Rail.

[1] Vide Minutes of Proceedings Inst. C. E., 1842, vol. ii. page 72.

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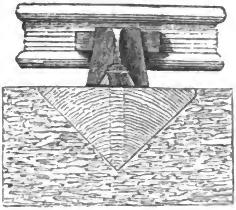
Fig. 11.

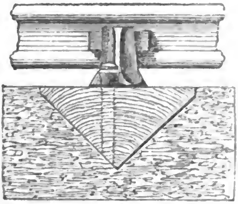
JOINT CHAIR.



End View.

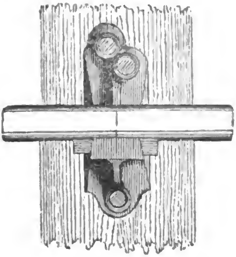
Fig. 13.

INTERMEDIATE CHAIR.



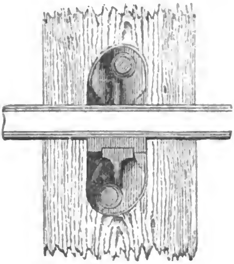
End View.

Fig. 12.



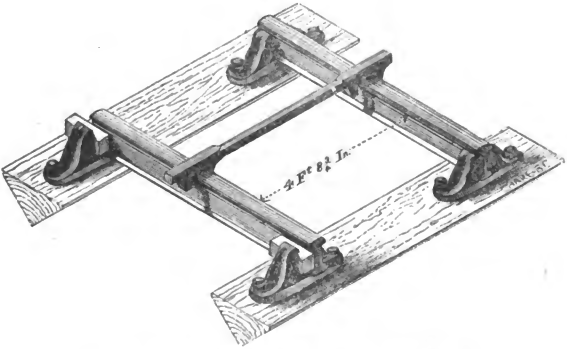
Plan.

Fig. 14.



Plan.

Fig. 15.



Rails, Chairs, and Sleepers, with the 'cramp gauge' fixed.

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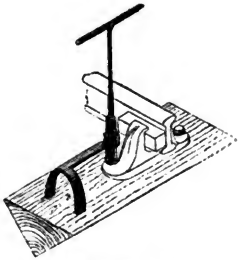
Fig. 16.



Guide-tube and Auger.

A simple mode of preparing oaken trenails has since been proposed. The ordinary round trenail requires to have the hole bored very accurately in the sleeper, to prevent splitting. The new mode is, to cast in the chair a trenail hole of an oblong form, say 1¼ inch by 2 inches in the direction of the grain of the sleeper, the upper side of the hole being as much larger than the lower, as is required to form the head of the trenail. A piece of straight-grained oak, not over dry, is driven into this hole, and is compressed, and the sap forced out in the act of driving. A hole 1½ inch in diameter being previously bored in the sleeper, the trenail is driven into it, and cannot split it, because it is of less width than the hole across the grain. But it drives very forcibly in the direction of the grain, precisely in the mode of a chisel-shaped brad, which forms its own hole without splitting, and it offers the greatest amount of resistance in the direction of the lurch of the engine. If chairs continue to be used, it is probable that this method will be found advantageous, as the square trenails can be prepared with greater facility than the cylindrical ones.

The wood keys should also have ample bearing surface, so as not to be crushed with the side-lurch of the engine.

Apart from the question of securing the rails to the sleepers, is that of the best mode of securing the ends of the rails to each other, so as to approximate to a continuous bar.

One of the earliest attempts to obviate the evils arising from insufficient connexion at the rail-joints, was on the Blackwall Railway.

In that case the rail-ends were connected together by a scarf-joint, about 6 inches in length, with the points dovetailed, and the whole wedged into the chair. As these rails were only used with

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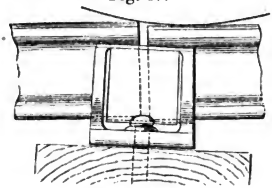
rope-traction, and were not tested by locomotive work, for which they were not intended, no deduction can be drawn from them; but they were weakened by the scarf, and were expensive in manufacture.

On examining the joints of a railway out of order, it will be found, that the forward end of each rail, in the direction of the traffic, stands, apparently, slightly higher than the hinder end of the rail in front of it (Fig. 17). When the weight comes on it, so as to press it down to the chair, it becomes the lowest, as the under part has been hammered in the chair, and the rail is reduced in depth. When once rails are thus hammered, it becomes impracticable to secure them firmly in the chairs, except by cutting off their ends.

Fig. 17.



Sunk Sleeper.

The joints of the rails are evidently the weakest parts of the line of way; therefore the great object is how to strengthen them; and this cannot be done by taking away metal from the already too weak part. Supporting the joint by extra sleepers appears a simple remedy, but the sleepers are not practically supports, as they only bear on loose ballast, and not on any continuous surface. It becomes necessary, then, to join the rails firmly together. The operation of 'fishing,' by the addition of pieces of metal to each side, then presents itself; but to secure these 'fishes,' becomes the next question. The simplest mode is to take the rail-joint wholly out of the chair, and to place a sleeper, with a chair on it, on each side of the joint, thus suspending the joint between the two chairs. The 'fishes' being then driven in on each side of the rails, the rails and chairs are connected together. This was practised by the Author in 1847.

The damaged rails were thus supported by the chairs in the undamaged part, and they were made practically continuous, while permitting expansion and contraction, by the sliding of the fishes. But putting the fishes into the chairs involved the necessity for fresh castings, and it was found a simpler operation to punch holes in the rails, and connect the fishes together by four bolts passing through all, the holes in the rails being larger than the holes in the fishes, to permit of expansion and contraction. The first fishes tried were of cast-iron, and they answered very well; but subsequently wrought-iron was substituted, the edges of the fishes bearing against the top and bottom of the web of the rail, leaving the middle untouched, so that the bolts were held as it were in spring tension endways, and

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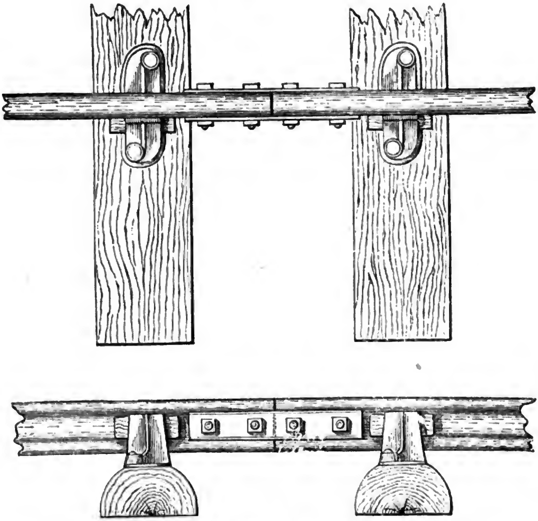
therefore did not work loose. So perfect was this arrangement, that old rails, which had become useless, when battered at the ends, so that one end projected nearly a quarter of an inch above the other, when once firmly connected by the fishes, gradually rolled, under the working of the trains, to a perfectly level surface.

This plan did not, however, get into general use, and the Author having many other subjects to occupy him, the matter lay in abeyance, but some experienced engineers, convinced of the efficiency of the system, became possessed of a portion of his interest in it, and have since been enabled to extend its adoption, with good practical effect, entirely confirming the soundness of the original views relative to it.

The application of the 'fishing-plates' to ordinary rails is very simply and rapidly effected, and the results are very satisfactory (Figs. 18 and 19).

The next proposition for improving joints was by Professor Gordon. It was, to make a horizontal lap, by cutting away 3 inches from the top of one rail, and 3 inches from the bottom of its neighbour, to half the depth of each, and then lapping them together

Fig. 18.



Fishing-plates applied to ordinary Rails.

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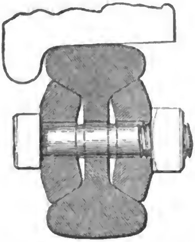
Fig. 19.



Enlarged Section of Rail and fishing-plates.

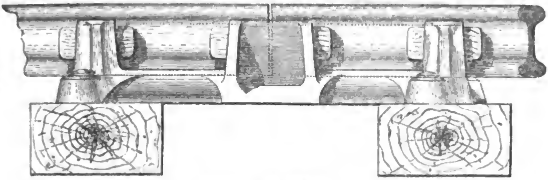
and securing them in the chair. It was expected that the hinder rail in the line of progress, thus lapping over the forward one, would keep both down together. But whether from bad iron, or from the diminished strength of the parts, it was found that the ends broke off, and the plan was abandoned.

At length, in the year 1849, the authorities on the Eastern Counties Railway resolved to try the experiment of the 'fish-joint.' Some half-dozen rails were jointed with cast-iron fishes, and they were found to answer.

Many persons went to examine them, yet though all appeared satisfied, the railway companies and the engineers exercised a wise discretion in waiting till experiment had become experience. Progress under such circumstances is slow, and, moreover, as the trial seemed to throw a new light on the question of good joints, many new experiments were made.

Mr. J. Fowler, M. Inst. C. E., produced a chair-joint, (Fig. 20,) formed of three pairs of jaws cast together upon a sole-plate, the two extremities resting upon two sleepers below: it is said to answer well on the East Lincolnshire line, and has been in use there since 1849. Various other plans also were tried, or suggested.

Fig. 20.



Fowler's Joint Chair.

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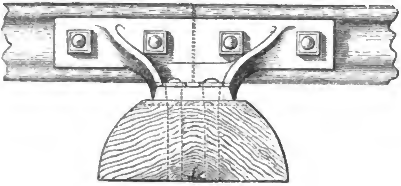
In applying the fish-joint to the repair of rails on lines, when funds had grown scarce, an objection arose to the cost of an extra sleeper and chair, in addition to the fishes. To meet this objection, Mr. Samuel contrived a modification of the 'fish.' (Figs. 21, 22, and 23.)

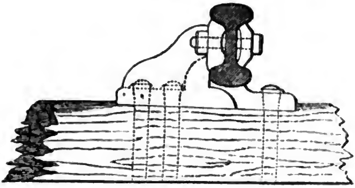
Fig. 21.

SAMUEL'S FISH CHAIR.



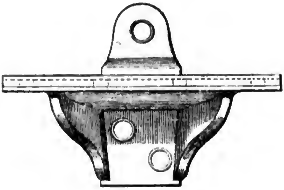
Side View.

Fig. 22.



Section.

Fig. 23.



Plan.

A chair was cast with only one jaw, made to fit against one side of the rails, a wrought-iron fish being placed against the other side, and all bolted together through the rails and fishes. This required only one sleeper, and the value of the modification of course resolves itself into a question of bearing surface on the ballast. If one

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sleeper be sufficient there is no use for two, but it would be an unwise economy to save sleepers and to expend more than the amount in maintenance of way.

In the original specification of the fishing plan, it was foreseen, that many evasions might be resorted to, and various modes of accomplishing the same object were suggested and shown. Double-headed chairs were specified, and also the mode of casting the chair-heads to fill the channels of the rails. A plan of splicing rails was also provided for. It was to roll the rail double, with a vertical joint from top to bottom, and to fix them together 'break-joint,' *i. e.*, with the joints of one pair of half rails, abutting on the solid portion of another half rail, so that the rail would practically be continuous, the rails being riveted, or bolted, or fished together laterally. It will of course require more iron to construct rails on this plan, than in the solid form; but, though hitherto unused in England, the system has been rather extensively used in the United States and in the colonies, and is frequently preferred to other arrangements, the rail being very quiet, the absence of solidity preventing any ringing noise.

An unwise economy has generally been practised, in restricting the quantities of Railway material, or fixed plant, though there has been no such economy in rolling stock. At the outset of railways, iron was the most costly commodity, and all methods were sought to lessen its consumption. This idea was continued as a kind of superstition, long after iron became cheaper, so that at the outset of the Author's experiments, he found, that to increase the weight of the permanent way was considered a kind of misdemeanour, to be avoided by any means, and a second chair to a joint was held to be a great extravagance, yet almost immediately on the production of the fish-joint, iron seemed to increase in quantity, and its cost to lessen in many ways. The quantity of cast-iron sleepers used on the South Eastern and the Midland Railways, appeared to have overthrown the superstition, and timber was suddenly pronounced to be wholly unfitted to be classed amongst the materials of permanent way.

Occasional breakages of cast-iron sleepers, owing to the desire to lessen the first cost of material, and thus unduly reducing its proportions, caused attention to be turned to the capabilities of wrought-iron.

The saddle-back rail of Mr. W. H. Barlow, previously alluded to, (page 6, Fig. 1,) was the first result. This rail is usually 13 inches in width, and 5¾ inches deep, and weighs 126 lbs. to the yard.[1] It

[1] The weight now generally used is 90 lbs. to 94 lbs. per yard.—*Sec. Inst. C. E.*

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is stated, that "it will bear a pressure of 40 tons without spreading out in width, and of 27 tons between bearings, 4 feet 4 inches apart, without its elasticity being injured; the stiffness of the rail virtually increases its bearing surface, for if a weight be placed over the centre sleeper of a length, and the rail be flexible, the whole of that weight will be borne by the sleeper, whereas, if the rail be rigid, the weight will be equally distributed over the adjoining sleepers."

If this rail be as rigid as it is described to be, with a proper extent of bearing surface, and is sufficiently heavy to remain quiescent under the rolling loads, there ought to be no cost of "maintenance of way," but only the expense of renewal from time to time. But upon examination it appears, that though the rail is 13 inches wide, this is not all true bearing surface. If the trough, or hollow, were filled with adhesive ballast, that could not leave it, the whole width would be bearing surface, but it appears to lie on the ballast as a saddle lies on a horse's back. It is stated, that considerable noise is experienced in running over this rail. If so, this would indicate a hollowness. In dry sandy ballast, however well the hollow of the rail might be packed, it must always be falling away from the upper part of the trough. Then again, the side surface to resist displacement, by the lurch of the engine, is but 4 inches, in a wedge form, tapering down to a sharp edge, like the form of a ploughshare. This want of hold must render the process of packing very difficult.

It is stated, that "in this wrought-iron rail, there is a sensation of hardness, which appears to result from the rails having been laid down a short time, and not having been worn to sufficient evenness on the upper surface." There can be no doubt, that the mere roughness, from the rolls, on the surface of rails, is sufficient to produce positive blows at high speeds, and were it practicable to produce a smooth surface on them, there would be a great advantage in it, not merely by the even face, but by hardening. But assuming the saddle-back rail to be a rigid girder, another consideration ensues. It is stated, by experimenters, that the limit of weight which can be borne by the best wrought-iron, before it begins to be crushed, is 11 tons to the square inch. Rail-iron has been stated to be only equivalent to 8 tons per square inch. But the impact of a driving-wheel with 7 tons weight on it, is only a point, and under favourable circumstances a line, unless the rail deflects and partly laps round the wheels. If this be correct, it follows, that a rail ought to laminate and roll out under heavy engines, as has actually occurred in many instances. Though it must be stated, on the

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other side, that there are many rails which have been down for years under heavy engines, and are still not injured, probably escaping lamination by elastic deflection.

If it be resolved to continue the use of inflexible girder rails, one of two methods must be resorted to. The first is, to make the rail of steel, or to steel the surfaces, and the other is, to increase the width. As the weight on the engine is greater than that on the train carriages, or waggons, it might be desirable to construct the rails with two surfaces, the double surface for the engines, and the single surface for the train, with a channel rolled between the two for the holding down bolts, which will be presently alluded to.

Reasoning on the absolute necessity, in regard to economy of maintenance of way, of obtaining an inflexible rail, that will not crush either the ballast, or the sleepers in detail, the question changes, from Mr. Barlow's rail to his mode of connecting his rail-ends together, for if the connexion does not produce equal strength with the other portions of the rail, mischievous results ought to ensue, unless the middle of the rail be three times the breaking, or deflecting strength, and the joint only twice, and then there is a waste of one-third of the strength of the rail.

The mode used is, to place below the two rail-ends a saddle of wrought-iron, about 2 feet in length fitting the trough. To this saddle the two rail-ends are riveted firmly at the outer edges, without any provision for expansion, or contraction. The upper portions of the rails abut closely together, and thus the lower part is in tension, and the upper part in compression, and the two together form a beam, the strength of which must depend on the power of the rivets to resist being sheared off.

Supposing the upper, or abutting portion to be removed, the lower portion with the rivets would be apt to bend under a load, consequently the strength of the joint must depend on the abutting ends and the strength of the rivets. If, therefore, there be any expansion, the rails must elongate through the whole length, and slide over the surface, or they will buckle upwards, or sideways. But it is said there is no expansion; and if so, it is possible that the contact of the earth carries off the heat as it is generated, just as water carries off the heat applied to the bottom of a boiler.

It would appear clear, that when the upper portion of this rail is worn by the traffic, a very large quantity of iron will have to be removed, and renewed. This of course is a matter for commercial consideration on one side, and of mechanical convenience on the other.

Assuming that, for certain purposes, the solid rail might be

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desirable, it remains to be proved that the saddle-back is the best form, either for strength, or for packing. Lateral and vertical stiffness, with large bearing surface vertically, and security against lateral shifting, are the objects sought for; and with these points in view, the T form section, with the rail, or rib, on the upper surface, appears be well adapted for general use. In this form there is a bearing surface horizontally of 14 inches in width, the total depth is 9 inches, and the depth below the horizontal surface is 6½ inches, giving great vertical stiffness, and serving as a keel to prevent lateral movement in the ground, the rail being used without any sleepers. To form the joints, two cheek-plates, about 2 feet in length, might be bolted to the vertical and horizontal portion, with allowance for expansion and contraction in the holes through the rails, which are made larger than in the cheek-plates. This rail would lie very firmly in the ballast, and the packing from the surface would be very easy, the vertical web forming a solid back to ram the ballast against. If it were required to key more firmly in the ground, a timber might be bolted to the lower edge. It might be objected that there would be a difficulty in rolling this rail, but practice decreases those objections daily; in fact, there is, practically, no mechanical difficulty to large demands. It might be objected to this rail that it might be noisy, but probably it would be less so than a trough-form rail.

If a quiet rail be required, without vertical deflection, it may be produced by rolling an upper table with a deep thin vertical web, and bolting it laterally between two timbers. To secure adhesion between the timbers, the sides may be rolled to the form of the planking of a clincher-built ship, multiplying in that mode horizontal bearing surface on the timber, or a T-formed rail may be used.

A webbed girder-rail may be used with transverse sleepers, without chairs, by adding to a foot-rail, a deep web, to be inserted to the depth of 3 inches in the sleepers, so that the feet rest horizontally on the surface of the timber and are fastened down by dog-head spikes. At the joints the rails might be attached together by plates fitting into a longitudidal groove rolled in the web (fig. 24). This rail, whose upper table would be only 2½ inches above the surface of the sleepers, would possess great vertical and horizontal stiffness, and would be a cheap and serviceable form of railway.

Solid rails, such as have been described, might be difficult to bend for curved lines, on account of their width; but by making a girder rail of several pieces, the difficulty may be overcome. A flat plate 14 inches wide may be bolted between a bridge, or foot-rail, at the top, on a T-girder below, the bolt-holes in the flat plate being disposed in the curved line required, and the rail and T-girder bent to

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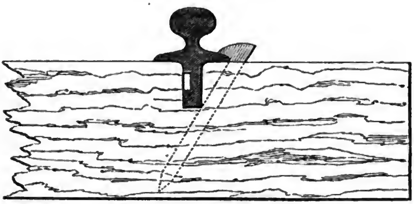
Fig. 24.



Webbed-foot Rail.

it. To make the joints, cheek-plates may be bolted laterally to the girder, and the rail break-joint with it. The bolts require to be strong, to make the girders firm.

Another variety of girder-rail is formed by a bridge, or foot-rail, bolted on two wide and deep angle-plates which break-joint with each other and with the rail, and thus no cheek-plate is required at the joints. This rail would be quiet, the division of parts preventing ringing. Many other varieties of form have been devised for particular localities.

The question of adhesion must be viewed from two different aspects. In driving-wheels, the maximum of adhesion, up to the propelling power, is required. In all other wheels adhesion should be got rid of altogether. The Author is not aware, that any experiments have been made, to ascertain whether the conical form of the periphery of the driving-wheels assists, or retards propulsion; but it is clear, that if a conical-formed tire presses over the whole width of the rail, with equal intensity, there must be a universal grinding action, which, even supposing it to be beneficial in the case of the driving-wheels, must be mischievous in all other cases. Therefore it is clear, that steel rails and cylindrical peripheries are mechanically desirable, in one point of view, for all bearing-wheels, unless other circumstances intervene, which render the friction a lesser evil in comparison with something else. That a considerable friction does take place, involving the rubbing of tires on rails, may be judged by the fact, that the rails in use, present a burnished appearance, and that after the passage of a train particles of metal resembling black-lead dust are found on the rail surface.

Experiments to determine this question of friction and adhesion on firm inflexible rails of iron and steel, and with conical and cylindrical wheels, are much wanted, and would prove valuable data for railway companies, involving as they do the question of diminution of cost of haulage and of maintenance of way.

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There is another subject, in railway maintenance, which appears to have been overlooked. Provision has been made for drainage, but not for drainage in immediate contact with the rail. It is known by experience, that the vibration of passing trains commonly opens a thinner, or thicker air-space, between the vertical edges of the sleepers and the ballast, when the weather is dry, and that into these portions of the way rain finds its way as to a drain. The sleeper being absolutely loose from all lateral adhesion, springs up and down beneath the trains, and packing is required. The oozing of the fine washed sand from the sides of the sleepers points this out to the way-men. Moreover, even in continuous rainy weather, the ballast being an absorbent material, or sponge, and the sleeper non-absorbent, the greater mass of water will be found at the point of contact, precisely as the water of gravel-beds is intercepted by a clay stratum.

Impressed with this defect, the Author was led to consider the practicability of getting the drains close to the sleeper, and the most obvious mode was, to make the sleeper itself the drain, by constructing it of perforated iron, or supposing iron rails to be used without sleepers, to make the rail itself the sleeper. The plan proposed to accomplish this is to roll a rail with a deep thin vertical web; two angle-pieces of cast, or of sheet iron, bent to the requisite form are bolted to the rail above and below, breaking-joint; these angle-plates are perforated, and the water will find its way through the perforations, precisely as it does in ordinary clay drain-pipes, and may be led away to the exterior at convenient intervals. The form of this rail will give perfect rigidity; and if perfect rigidity be compatible with durability of the running surface—a point not yet satisfactorily made out—and if the bearing surface be in excess of the load to disturb it, it ought not to require any maintenance of way. In using the term rigidity, it must not be understood as applying to a torsive strain, such as an engine flanch would tend to produce, as it would have a slight elastic yielding in that direction. The packing of this kind of rail would be exposed to the same difficulties as ordinary longitudinal, or transverse sleepers, from the depth of bearing below the surface; but this might be obviated by reversing the angle, and placing the flat above, as in the triangular sleepers of the Dover line. Or the two sides might be curvilinear, for the purpose of inducing more stability, and preventing rocking on the ballast.

A copious use of water would do away with the annoyance of dust, and be economical for maintenance of way.

Supposing a rigid rail to be impracticable, on account of lamina-

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tion, it will become necessary to devise a mode of producing yielding, or vibration of the upper surface, without in any way disturbing the portion which rests on the ballast. For this purpose, the Author would propose to use a rail with a deep thin vertical web, bolted so as to break-joint, between two angle-plates at the upper portion, as before described, but with a space between the bottom of the rail and the bottom bearer. If the rail deflects, it must, on account of its great depth and fastenings, deflect only on a considerable length, and that without disturbing the bottom. If the pressure be excessive, it will take a bearing on the bottom and will in fact be a spring-rail. The bottom may be of cast-iron, but in all cases it will be sufficiently solid to prevent its yielding in the central part.

The girder-rails, or sleepers, thus described, are in common with the trough-rail subject to a defect. They are mostly of wrought-iron and therefore liable to oxidate. If this be a serious objection, it may be remedied by a coating of zinc, or other metal, or by bituminizing, or covering with mineral paint, or coal-tar.

How far such a principle of rail might be available as a pipe for the transit of water, for other purposes than watering the road, is a matter for consideration.

In the American Union the railways run through the streets of towns. It has hitherto been found difficult to construct a line of this kind, so as to bear the rough usage of carts and waggons that run over the rails in every direction. Some of these lines are constructed of heavy cast-iron, and cost as much as 24,000 dollars per mile, equivalent to nearly £5,000. It would appear probable, that solid girder-rails of wrought-iron, such as have been before described, would be found to answer the purpose.

With regard to the applications of "permanent way" on the Continent, two patterns appear to have been set. One, the American pattern of the foot-rail and longitudinal balk, fastened by dogs, which prevails very commonly in Germany; the other, the English double T rail and chair with transverse sleepers. In France, the English system is the general type. But the American system has scarcely been used in England, save by contractors, for temporary work. It has, however, been stated, that longitudinal timber sleepers on stone foundations, have been found to form the most really permanent way of any used in the United States, where "maintenance," on account of the high price of labour, is a very costly item.

In speaking both of the longitudinal and transverse sleepers, the combined systems, partially introduced, have not been alluded to. In truth, the rail being rendered non-deflecting, the other consider-

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ation is, how can it best be secured to a sufficient mass of bearing surface on the ballast, to secure it against sinking? With a non-deflecting rail, it is a matter of no consequence, whether the bearing surface be equally distributed, or be placed upon sleepers, like piers, save that, the farther the bearings are apart, the stronger and heavier must be the rail and the sleeper, or pier foundations.

In discussing the durability of way, the question of constructing the levels and the inclines, forms an important item.

Supposing a line to be required to be worked by fast, or express trains, not stopping, and by a number of other trains, stopping at very frequent stations, the plan is occasionally resorted to, of making sidings from the main-line, at the stations, in which the stopping trains may pull up, while the express trains may run by unimpeded.

In starting the trains from the stations, great surplus power is required, and in arriving, great damage is done by the friction of the stopped wheels on the rails. But if it were practicable so to arrange it, that the main line might be on the level, while the sidings, or stopping stations, were on an elevation, less engine-power would suffice to start and to work the trains, and no break-power would be required to stop them. The artificial levels might easily be arranged, by constructing the stations on brick arches alongside the main line, and letting the siding road run over the arches, which would form summit levels, the offices being below. And by a proper disposition of rails on elastic timber, the vibration might be sufficiently diminished, bearing in mind also that no rapid movement would exist on the immediate summit.

The question of permanent way in Egypt, India, &c., involves some new considerations. Railways, in themselves evidences of a high state of civilization, are unquestionably, calculated to become the most effective implements for bringing semi-barbarous countries into a state of civilization. But as railways, in such countries, must pass through wild districts, thinly peopled, where fences and police cannot be maintained, and where, in many cases, the whole line must, in fact, be a level crossing where most people are pilferers, it becomes necessary to revert to such means as may place the railway in such a state, that it will watch itself in considerable length, without needing fences, or police, by having nothing practicable to pilfer.

In Egypt, up the valley of the Nile, there can be no need of these precautions. He would be a bold thief who would venture on appropriating any railway material belonging to Abbas Pasha. But there are other circumstances to contend against. The dry heat of the atmosphere is fatal to timber, and the soil along which the

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Egyptian line will be carried, will vary from the extreme moisture of irrigated land to parched dust. Therefore, the deeper the foundations of a discontinuous sleeper road can be placed, the better chance there is of their remaining firm. What the effect of Mr. Barlow's saddle-back rail, or of girder-rails, would be, in such a climate, with an intense sun by day and with condensation by night, would require some careful experiment to determine. It is probable that ample provision for expansion and contraction would be required. In this case, a hollow girder-rail, with a free current of air through it, would be the best adapted for maintaining an equal temperature. Any of these kinds of rails, without timber, and with few parts, firmly fixed together, would offer little temptation to a marauder.

In hot climates, well peopled, when once introduced, railways will multiply as a means of health. They afford the most efficient means of obtaining the coolness, essential to keep down fever, and however stagnant the atmosphere may be, a locomotive at speed can always produce on a train of passengers the effect of a cooling breeze.

Such will eventually be the result of railways in the East. As the sea-breeze is called the 'Doctor' in the West Indian Islands, so will the railways of the East acquire similar names. The wealthy will make moving houses on the eastern railways, for the sake of an artificial climate wherein their jaded faculties may be restored.

In the flat parts of India, there are two evils to be guarded against; the flooding of the ground at seasons, which might float up a line, in which much buoyant timber was used, and the other is the white ant. It is doubtful, however, if the white ant would not find creosote disagree with his taste, quite as much as the teredo navalis finds it impede his tunnelling operations. It is apprehended, however, that all timber, in arid climates, would require to be well covered with ballast, to prevent injury from the hot cokes, from the ash-pan.

If broad flat stones could be used without ballast, and at a small cost, they would form a most valuable foundation; but stones cannot be used without timber, and fastenings, and therefore it seems probable, that continuous wrought rails of the compound girder form, may be best adapted for such circumstances; and if they be made wide enough to take an efficient bearing, on ordinary ground, as plank roads are made in America, they may be found the cheapest structure, and at the same time, a structure that manufacturers could turn out complete from their establishments, and which would require no skilled labour to apply.

It must be received as an axiom, that even where wood is

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plentiful, it is not a cheap material. It requires much skilled labour to apply it—unless the form reduces it to machine work—and if the wood be hard it is very costly, and if soft, it has little durability, save by creosoting.

Girder-rails of sufficient size will probably be largely used in our Australian colonies, where, as in America, they cannot afford to pay policemen, and they require a structure, not easily damaged by carelessness, or wilfulness; a structure also, be it said, that affords peculiar facilities for moving from one district to another, if by change of circumstances a more eligible route were found, for be it remembered, that in such districts the bare 'way,' and the 'siding,' constitute almost the whole property of the railway.

The cost of the various kinds of structure examined, has not been here entered into, because it must vary with the locality, and the quality of the material; and the structure which is cheapest in one place may be dearest in another. It is also well understood, that cost depends chiefly on quantity, in a material practically without limit, such as iron.

An apology is perhaps due for the prolixity of this paper, recapitulating many things familiar to engineers; but when reflecting that the permanence of way must depend precisely on the details of its structure, and the care that is taken to guard against deteriorating causes, and which may sometimes make all the difference between a dividend and a loss, those who examine deeply will not consider the prolixity a waste of time.

In some of the views which he has taken, or rather in the elaboration of principles which must have occurred to all who have had time to think, the Author would disclaim all captious criticism. His object has been to arrive at mechanical truth, and to indicate in what direction further experiments should be made, in furtherance of railway progress, which is another result of the instinct that has prompted the great Anglo-Saxon race to push steadily forward, in this great work of civilization. For in truth the road is the great civilizer of humanity. People only quarrel with those they do not know. Give them access to each other and the quarrels cease. It is a marvellous instinct that prompts this law-loving nation and its offshoots to the work of road-making, and if he who makes two ears of wheat grow, where only one grew before, be worthy of an ovation, what shall be said to those, amongst the noble array of engineers, who will make two lines of railways at the cost of one?

The absence of roads is isolation, and if by some strange chance England should be deprived of her roads, and be prevented from reconstructing them, another generation might behold the inhabit-

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ants reduced again to the condition in which they were found by Julius Cæsar.

From this state, roads have delivered us, under the dispensation of Providence, giving latent faculties to man. The most perfect road yet known is the railroad; and no higher service can be done to humanity than making railroads still more perfect, thus removing the chief obstruction to man's universal interchange of ideas, and the general spread of the benefits of civilization.

The paper is illustrated by a series of diagrams from which the woodcuts have been compiled.[1]

Mr. W. B. Adams described the different sections of rails, of which diagrams were exhibited, and directed attention to a girder-rail of simple construction, hollow, so as to preserve as nearly as possible a uniform temperature, under the extreme thermometric variations between day and night, or even to serve as an occasional conduit, and also as a conduit for water, which latter, it was contended, might be advantageously employed in preventing the clouds of dust from which the passengers now suffered inconvenience, and at the same time causing more permanent contact between the ballast and the supports of the rails. This, he submitted, would be an efficacious, simple, and cheap mode of constructing the permanent way.

Mr. P. W. Barlow objected, that the question of the cost of the permanent way had been almost entirely lost sight of, in the paper; now this was so important a consideration, in all constructions, that it should have been fully considered, before entering on the discussion of the various expensive innovations alluded to by the Author.

With respect to the system of cast-iron supports, for which he was responsible, it was necessary to state, that it had been proposed, before it was considered practicable to roll rails, either of such weight, or of such an extended section, as those introduced by his brother, Mr. W. H. Barlow, and now known as the 'saddle-back rail;' as soon as it was found, that such rails could be manufactured, he had advised their being tried, and he was fully satisfied with the result. Previous to that time, however, being under the necessity of determining the construction of about sixty miles of line, he had not hesitated to employ the cast-iron supports, which had, under the circumstances, fully answered his expectations. It must be admitted, however, that the saddle-back rail was, under ordinary circum-

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[1] Several of the blocks, for the cuts, have been lent by members.—*Sec. Inst. C. E.*

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stances, preferable; a single line of way could be laid with those rails, weighing 90 lbs. per yard (at the then low price of iron), at a cost of £900, or £1000, per mile. The portions of line so constructed, on the Midland Railway, were very successful; there was an even motion in the carriages, less noise at the joints, and evidently less wear and tear in the rolling stock, in spite of the rigidity of the rails. He apprehended, that the expense of the 'maintenance of way' would be considerably reduced.

Mr. W. B. ADAMS submitted, that the question of cost need not necessarily enter into the discussion, especially as the prices of materials were constantly varying, and the quantities being given, each engineer could make his own calculation as to first cost.

Mr. BRUNEL said, he was so fully impressed with the necessity for attempting to reduce the expense of maintenance of way, that he had not hesitated to try the 'saddle-back' rail, and as far as the limited experience of only twelve months enabled him to form an opinion, he was well satisfied with the result of the experiment, for although it had not yet induced the happy position, assumed by Mr. Adams, of there being 'no cost of maintenance of way,' there was every indication of considerable economy in the ordinary expense of repairs. The piece of railway, where the experiment was tried, was about seventy-five miles from London, and exposed to all the traffic of the Great Western Railway, under somewhat disadvantageous circumstances; yet it appeared to stand well, and, at present, the expense of maintenance of way was quite as low as that for the system of bridge-rail, with longitudinal timber-sleepers. It was well known, that Mr. Brunel was a decided advocate of the latter system of construction; he believed a line thus made to be at least as easily kept in order as with transverse sleepers; the joints were as readily made and were more solid, than those of any other system, and the cost of the original construction was not greater. The saddle-back rail appeared to possess most of these advantages, and at the same time to offer economy in the first cost; the joints, in particular, were rendered very even and secure, by fastening the ends of the rails upon a wrought-iron saddle-piece, with four, or six rivets, which united them perfectly.

He was so satisfied with the general result, that he had also used these rails on a short length of twelve miles, on a railway in Cornwall, and was about to adopt them for a considerable length on the South Wales Railway.

He must observe, that in the description, given by Mr. Adams, of the effect of traffic on bridge-rails and longitudinal bearings, results were mentioned which, during all his experience of the

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system, had escaped his notice. The actual results of his first trial of the system were these;—the rails were too light, and being only attached to the timbers by a large sort of ordinary wood-screw, traversing the flanch of the rail and passing nearly through the timber below, the deflection, or 'creep' of the rail loosened the screws, and after being tightened down a few times, the holes became galled and the screws no longer held firm. They were then abandoned and were replaced by screw-bolts with the nuts on the under side of the sleepers; these in turn were reversed, the nuts being screwed on from above, and thus were accessible for constant examination; the corners of the heads were turned up, like fangs, to bite into the timber and prevent the bolt from turning.

When the bridge-rail was well bolted down, with small joint-plates, introduced beneath the junction of the ends, no system could give a smoother way for the carriages, or generally succeed better; it was, however, more expensive, in first construction, than Barlow's saddle-back rail.

It was generally considered necessary, in laying rails, to provide for their contraction and expansion. Now, however strange the assertion might appear, Mr. Brunel did not hesitate to state, that such provision was unnecessary, under ordinary circumstances, in this climate. This would become evident, when it was considered that 10° or 12° of heat only represented an amount of expansion equal to 1 ton per square inch of pressure; now if the rails were held very firmly by their fastenings, there would be sufficient resistance to counteract any effect of contraction, or expansion, between the points of attachment, as a change of temperature of even 50° would only render it necessary to provide for a tension, or compression equal to 5 tons per square inch in the whole, or 2½ tons alternately, of extension and compression.

A fact had been mentioned to him, by Mr. Hawkshaw, relative to a cast-iron parapet, which completely confirmed this view, and it was found, that in riveting together the ends of the bridge rails, the same effect was produced. When this was first mentioned, everybody doubted it, and to satisfy himself, Mr. Brunel caused a length of 100 feet of rails to be welded together, and another length of a quarter of a mile to be riveted together, with accurate gauges fixed at each end; the result was conclusive, that there was not any accumulated motion, either at the extremities, or in any part of the two lengths. This and other subsequent trials convinced him, that it was only necessary to fix the rails securely upon steady sleepers, to provide against every tendency to contract, or expand, arising from the variation of temperature in this climate, although in a very hot

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summer he had found the surface of the rail heated to as much as 130°.

With respect to the various modifications of the forms of rails, proposed by the Author of the paper, in the diagrams exhibited, and with every desire to remark courteously on the papers kindly prepared for the meetings, he must say, that he could not find any suggestions calculated to advance the practice of laying permanent way. They might be ingenious, but they were not useful, and most of the forms had been already tried and condemned.

As to the split-rail, stated to have been tried in America, there was no experience of its use in this country, to enable an opinion to be hazarded upon its utility. The arguments in favour of the girder double rail were based upon assumed, but not demonstrated, defects in the saddle-back rail, and it did not appear that any experiments had been made, to prove either the positive existence of the defects, or of the merits of the proposed plan for obviating them. It was presumed, that the saddle-back rail did not take a solid bearing on the ballast, in consequence of the difficulty of packing it; now it was well ascertained, that ballast of almost any kind became, in time, so perfectly rammed into the cavity, that a nearly solid mass was formed, whereon the spreading flanches took a solid bearing, at a sufficient depth to receive the necessary lateral support, without that hindrance to perfect drainage which would be likely to occur from an extreme depth of web, unless there was such a thickness of ballast as would be very expensive in practice. On the other hand, the shallower proposed forms had the disadvantage of taking their bearing so near the surface, that the packing would be affected by any slight changes of weather.

With good materials, and judgment and care in applying them, a practically perfect permanent way could be made, either with stone blocks, or transverse sleepers and chairs, or with longitudinal timber-bearings and bridge-rails, and any of these systems were preferable to the proposed modifications; but Mr. Brunel hoped, that with Barlow's saddle-back rail a permanent way as good, or nearly as good as any of these, might be constructed, and at a less cost.

Mr. Ashcroft said, from his experience of the system of 'fishing' the ends of the rails, on the Eastern Counties Railway, where it was already tried upon a length of twenty miles, he was of opinion, that there would be an economy of fifty per cent. in the cost of maintenance of way; and he thought, that by the application of the 'fishes,' to retain the ends in the same plane, and to render

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them steady under the wheels, any line, with transverse sleepers and chairs, could be cheaply put into, and be easily retained in, good working order.

Mr. Bird said, he had been informed, by eminent German engineers, that 'seite laschen,' which were nearly identical with the 'fishing-plates,' had been used for several years in Germany. On the railway between Leipzic and Dresden, which was nearly the first line executed in that country, having been constructed in the year 1838, a portion was laid with single T rails and 'seite laschen,' holes being punched in the ends of the rails for these fastenings. They had subsequently been employed, throughout the entire length of the Lubeck Railway, and were tried on many other lines; indeed the 'seite laschen' were included in most of the specifications; their form was such as to allow them exactly to fill the cavity on each side the rail, immediately beneath the top table, and they were held together by transverse bolts and nuts. On the railway near Olmutz, in addition to the 'seite laschen,' the two lines of rails were connected transversely by long bolts, to preserve the gauge accurately. In Rhenish Prussia the ends of the rails were connected by 'seite laschen,' of such a form as to adapt the upper part to the vertical web of the rail, and with a horizontal web to be attached to the sleeper. He was not aware, that in any part of Germany fishing-plates, between the supports, had been adopted.

Mr. Samuel was not aware of the 'fishing-plates' having been adopted in Germany, otherwise than as a means of keeping together the ends of the rails in the joint-chair, of which they merely extended the hold on each side. He had never seen them used, in Germany, with the suspended joint, in the manner he had employed them on the Eastern Counties and other lines.

He gathered from the paper, that Mr. Adams claimed the invention of the fished suspended joint; the claim was perfectly valid, and Mr. Samuel had become first connected with it, by introducing it practically on the Eastern Counties Railway. He subsequently used a 'fished-joint chair,' which he considered a valuable modification of Messrs. Adams' and Richardson's 'fish-joint;' it was capable of easy application to the permanent way of a line of the ordinary transverse sleeper construction, and had the merit of avoiding interference with the usual position of the sleepers and rails, which became inevitable, when the ordinary 'fishing-plates' were applied to a permanent way already laid down. The result of the experience of several miles, laid on this system, on the Eastern Counties Line, had been very satisfactory.

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Mr. BRUNEL had always understood, that it was to Mr. Samuel the railway world was indebted, for the valuable introduction of the 'fishing-plates' with the suspended joint, and all who had noticed the even surface of the rails and the smoothness of the travelling, on the portions of the lines so treated, must admit the great advantages of the system.

Mr. P. W. BARLOW would correct an impression which appeared to obtain, as to the extent of fracture of the cast-iron bearing-plates on his system; now the fact was, that the amount of breakage did not exceed that of the cast-iron chairs, on railways of the ordinary construction. He was convinced, that under all circumstances, the cast-iron bearing-plates could be economically employed, and this opinion was confirmed by the offer of Mr. Taylor, the contractor, to maintain and renew, for twenty years, that portion of the South Eastern line, laid with cast-iron bearing-plates, for £100 per mile per annum. It must be borne in mind, that the portion of line alluded to, was that on the Greenwich and the main line, where, from the confluence of so many trains, the traffic was nearly three times as great as the average of that of the other portions of the railway; and also, that the rails had been more than ordinarily degraded, from the employment of bad ballast.

In a Report he had recently made, on 'Permanent Way,'[1] he had given the details and the results of some extended experiments, having for object, 'to ascertain whether the weights of iron required to obtain the necessary bearing surface, and, at the same time, to insure against fracture, would make the cost greater than the value of the increased durability of the material;' and without troubling the meeting by a recapitulation of the particulars of the Report, to which he would beg to refer them, he would confidently state, tha the cost was even less than that of an ordinary wooden road.

The experience he had, in the maintenance of way, convinced him, that after the selection of a good quality of ballast, the cost of maintenance of a line depended on the extent of bearing surface, which should be so obtained as not to interfere with the drainage. It would appear, that in the commencement of the railway system, the engineers had admitted this fact, as with five stone blocks, each 2 feet square, at intervals of 3 feet from centre to centre, under each rail of 15 feet in length, there was an extent of bearing surface of 40 feet, under each pair of rails on a single line. On some of the more recent railways, with transverse timber-sleepers, the extent of

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[1] Vide Report on Permanent Way, by Peter W. Barlow, addressed to the Directors of the South Eastern Railway. 4to. London, 1849.

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bearing surface did not exceed 24 feet, part of which was useless, as the plate-layers only packed about 18 inches on each side of the chair. In the estimate of cost of his system of cast-iron bearing-plates, he assumed 28 feet of surface, and he believed that would be found sufficient for heavy traffic, as from the proximity of the base to the surface of the ballast, complete drainage could be obtained.

He understood it to have been stated, that the actual cost of maintaining the transverse timber-sleeper permanent way of the South Eastern Railway, had not exceeded £30 per mile for six months. He must be permitted to observe, that it was very possible to reduce present expenditure, at the risk of deterioration of the road, and that half a year was a very limited period to judge from.

He had tried two small pieces of line laid with Greaves' iron-sleepers; on one piece, no breakage occurred, but on a part of the railway, where the heavy engines passed over at full speed, several of the castings had been broken; he thought they had been made too light to bear the severe test of heavy engines, with hard gravel ballast upon brick arches. They were generally reported to stand well, requiring less repair than the ordinary sleepers. The cost of Greaves' system, if equal strength of metal was used in the sleepers, was necessarily greater than Mr. Barlow's cast-iron bearing-plates, with equal bearing surface.

The quality of timber employed for the sleepers, and the mode of preserving them from decay, were important questions, in the maintenance of permanent way. He believed the most economical system was, to use only the soundest timber that could be obtained; and after trying the processes of Kyan, Payne, and Burnett, he must admit that the only one which had not completely failed was Bethell's process, which was saturation with creosote.

Mr. W. H. Barlow explained, that the introduction of the saddle-back rails, on the Midland Railway, arose from the great expense incurred in renewing the timber-sleepers. In the first instance, he proposed a rail weighing 127 lbs. per yard, but in spite of the exertions of the manufacturers, for which they were entitled to great credit, the difficulty of manipulating such masses of iron was so great, that, as a temporary expedient, a length of about nine miles was laid with cast-iron bearing-plates, beneath rails weighing 80 lbs. per yard; the weight of the bearing-plates was about 300 tons per mile, and although the road was laid under circumstances of considerable difficulty, it had completely succeeded, and he would not desire to have a more perfect length of line; the

maintenance of a portion of this length had recently been let to a contractor, for £42 per mile per annum; this demonstrated the economy of the system. The rails were 20 feet long, with two rigid cross-ties, formed of bars so deep and stiff as to maintain the bevil of the rails, which was a very important feature in all permanent way.

As soon as the manufacturers had completed their arrangements, a length of way was laid with saddle-back rails, weighing 127 lbs. per yard, resting on cast-iron joint-plates, into which the rails were keyed; this formed a very durable road, requiring very little maintenance. Subsequently, finding there was an excess of strength, the weight of the rail had been reduced to 100 lbs., and was now being still further reduced to 90 lbs. per yard, the joints being made by riveting the meeting ends upon an internal wrought-iron saddle-piece, somewhat similar to that used by Mr. Brunel and Mr. Hawkshaw, for bridge-rails on longitudinal timbers.

The traffic of the Midland Railway was, from local circumstances, peculiarly heavy, and like all narrow-gauge roads, laboured under the disadvantage of the want of base so requisite for heavy traffic and high speeds; the cross-ties had therefore been extended on each side beyond the rails, and with considerable advantage.

The cost of a line, with saddle-back rails weighing 90 lbs. per yard, when those rails were costing £6 per ton, was £2,100 per mile for the two lines of way.

Mr. W. B. Adams had assumed, in his paper, that the permanent way was a constant source of expense, arising chiefly from the deflection of the rails, and the sinking of the sleepers, under the pressure of the passing loads. These effects, he argued, could only be obviated, by giving to the permanent way a certain amount of rigidity, upon an elastic absorbent, which would be best obtained by using deep stiff rails like girders, with lateral strength, and plenty of bearing surface on the ballast, so as to avoid the undue depression of the substratum. For these reasons, although, he believed, not strictly in accordance with the regulations of the Institution, he had ventured to suggest some hitherto untried forms of rails and methods of supporting them, which he felt convinced would attain the end which was admitted to be very desirable.

Captain W. S. Moorsom, in reference to Mr. Brunel's observation, was of opinion, that only under peculiar circumstances, could the usual precautions, against the effects of expansion and contraction, be dispensed with. The experience of Mr. Brunel and of Mr. Hawkshaw was certainly conclusive (as far as it went), but on the other hand, there were many instances of lengths of line being forced

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out of gauge, or lifted up, on sudden changes of temperature, owing, it was supposed, to the rails being too firmly fixed in the chairs. He had seen a length of nearly half a mile so lifted, on a railway under his charge; he therefore again recommended caution in disregarding the effects of changes of temperature.

The general questions of the first cost, and of the subsequent expense of maintenance of the permanent way, were of vital importance in railway economy, but he thought more details should be given, to enable a correct appreciation of the value of the various systems to be arrived at. The cost per mile of Mr. Barlow's saddle-back rail appeared low, but probably the amount stated only included the rails and the labour of laying them, without the ballast. This should be distinctly explained.

The data essential for making a comparison between the first cost, and the subsequent maintenance of different systems of permanent way, should comprehend—

1. The weights, and quantities of the respective materials.
2. The prices of the same—in place, and the amount per mile.
3. The character of the ballast.
4. The description of engines used on the road.
5. The number of trains—per annum.
6. The speeds.
7. The length of way subject to this traffic.
8. The time during which the expense of maintenance had been experienced.
9. The cost of maintenance per mile, per annum, including all materials and ballast.
10. The cost of maintenance, per train, per mile run, per annum.

As an example of his meaning, he would give a sketch of the particulars of the construction of the Waterford and Kilkenny Railway in 1846, when iron was at the high price of £12 per ton.

The sleepers were continuous longitudinal bearings of half balks, cut to an isosceles triangular section, with stiff cross-ties forming struts also. The double I rails weighed 56 lbs. per yard. The chairs, cast by Messrs. Ransomes and May, of their ordinary pattern, but with a parabolic section on the length of the bed, weighed respectively, for the joints, 27 lbs. each, and for the middle bearings, 14 lbs. each; the saddle-pieces weighed 7 lbs. each. The lengths of bearing varied from 30 inches, in the middle, to 15 inches at each end of the rails, before reaching the joints.

The first cost of this permanent way, if the rails cost £7 per ton,

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the chairs and saddles £5 per ton, and the timber for the sleepers 1*s.* 6*d.* per cubic foot, would be per mile of single line of way—

Rails	£ 616
Chairs and saddles	143
Pins, trenails and keys (Ransomes' and May's compressed)	87
Timber-sleepers, ties and dowels . .	453
Cost of laying	88
Total cost per mile . . .	£1,387

The railway, about thirteen miles in length, with a gauge of 5 feet 3 inches, had now been regularly travelled over, for between three and four years, by eight, or ten trains daily on each line, making about three thousand trains per annum. The weight of the locomotives used was about 22 tons, and the average speed of the trains was twenty-four miles per hour.

The cost of maintenance of way, including the renewal of all materials and ballast supplied, since the line had been out of the contractor's hands, had been, for the first year, £53 12*s.* per mile; for the second and third years, £35 12*s.* per mile; and for the first half of the current year, at the rate of £31 per mile per annum, or at the rate of 2·51 pence per mile run, per annum.

He believed this cost of maintenance was less than that of many lines of equal traffic.

Mr. R. J. Hood thought it was almost impossible to draw an accurate deduction, as to the comparative cost of maintenance of way, from any published reports, as it was rarely stated what was included under that head; for instance, on one line it was strictly limited to keeping up and renewing the lines of way, the ballasting and the ditches; whilst on another line the keeping up the fences would be included, and perhaps on account of the vicinity of the line to populous districts, the fencing was of an expensive kind. He agreed with Captain Moorsom, in the necessity for specifying everything very clearly.

As to the modifications of forms, proposed in the paper, they appeared to be chiefly untried attempts, to remedy some of the acknowledged evils of existing systems, but he could not agree in commending them.

Cast-iron sleepers had been laid down to some extent on the Brighton Railway, but Mr. Hood dreaded the expense of repair and of their renewal, or, what was more probable, the substitution of

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some other system. There were also, on the same railway, some bridge-rails laid on transverse sleepers; it was not a satisfactory system, and was frequently out of repair.

The 'fished' suspended joints were decidedly the best, even with only four, instead of five sleepers; he used 'fishing-plates' 18 inches long, with four transverse bolts ⅞ inch diameter, and found the surface of the rails so even, that the rolling stock was less injured than before their adoption. He was certain that system would diminish the cost of maintenance of way.

Mr. Hawkshaw corroborated the statement, as to the apparent absence of expansion and contraction, in lengths of iron securely tied down. About ten years since he erected at the station of the railway, at Salford, a parapet 750 feet long, composed of cast-iron plates, each 9 feet long, and 1 inch thick, firmly riveted together, and held down tightly; it retained a perfectly straight line, under all variations of temperature, without any special provision being made for contraction, or expansion.

He commenced using the systems of fishing rails, and of riveting them firmly together in long lengths, as far back as in 1846: one end of the joint-plate being riveted to the rail in the works, and the other on the line, when in place; no ill effects had ever been experienced, on his lines, from changes of temperature.

When rails were driven hard up endwise against each other in the joint-chairs, without there being fishing-plates to keep them down, and in the same plane, there was when under expansion a tendency in the rails to rise. The best feature of the fishing-plates was their power of holding the ends of the rails firmly down, and of keeping the travelling surface even.

The question of the relative cost of maintenance of way could not be properly discussed, without a minute detail of all the dates and circumstances. For instance, a line under his charge was constructed for some miles across a coal district, where, in consequence of the under-ground workings, the surface constantly subsided, and, of course, a large quantity of ballast was required to restore the level, independent of the constant labour in packing and keeping up the line for the traffic. The mechanical questions of good forms and proportions, of good quality of materials and of ballast, and of care in construction, were now generally well understood, and the best systems were acknowledged to be the cheapest in the end. He must repeat, that the cost of the maintenance of way was so dependent on a variety of circumstances, that it was extremely difficult to form a comparison between any two lines.

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After very extensive experience of almost all ordinary forms of rails and systems of construction, he gave the preference to a strong bridge-rail, firmly attached to longitudinal bearers of sound balk; this he, at present, considered as the best system of construction. He did not think that the fibre of the longitudinal timber-balk was more crushed under the bridge-rail, than that of the transverse sleepers under the chairs; and he believed the cost of maintenance of way to be somewhat less with longitudinal, than with transverse sleepers.[1]

He had used Greaves' cast-iron sleepers successfully, and he was of opinion, that in certain situations, particularly where the sand was used for packing or the gravel ballast was small, the system would answer well; on some foreign railways they would be found useful; particularly in the East, where only such timber could be used as was known to resist the ravages of the white ant, and there it was sometimes expensive and difficult to be obtained.

Mr. C. May directed attention to the joint-chairs, slightly alluded to in the paper; cast in 1849, by Messrs. Ransomes and May, at Ipswich, from the design of Mr. John Fowler, M. Inst. C.E. The object of the extended chair was, to prevent the injurious effect on the rolling stock, and permanent way, arising from the ends of the rails being permitted to move, as in the joint-chairs of the ordinary construction. This evil had been felt by all engineers, and there were few who had not attempted a remedy. Mr. Fowler had tried an experiment on one mile of line, under very considerable traffic, and, after an experience of two years, he expressed himself satisfied, that there was less action at the ends of the rails, which were held down more firmly, the injurious effects on the rolling stock were diminished, and the cost of maintenance of way had been reduced.

This joint-chair (Fig. 20, page 261) was 2 feet 6 inches long, and had three jaws on each side, so as to hold the ends firmly for 15 inches of each rail, giving that length of solid bearing.

Experience had shown, that the body of the chair might be shortened about 9 inches, without diminishing its utility, as its length was determined by the power of properly packing the two sleepers on which it rested. Only three chairs had been broken, in two years, and those all near the same place, showing that a slight addition of metal to that part would be beneficial.

It was not contended, by Mr. Fowler, that this was the best

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[1] In Mr. Hawkshaw's Report on the Rolling Stock and Permanent Way of the Lancashire and Yorkshire Railway, for Manchester, 1850, these points are discussed with great minuteness.—*Sec. Inst. C. E.*

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method of securing the end of the rails; but as it had proved successful, and it was not the object of a patent, he had requested Mr. May to lay the facts before the meeting.

Mr. WILSON corroborated the statement relative to Mr. Fowler's joint-chairs; they had been used, in 1849, on the Lincoln branch of the Manchester, Sheffield, and Lincolnshire Railway, where there was considerable traffic, with heavy engines, and at high speeds; they were subjected to severe trials, by running engines, at considerable speeds, over obstructions ½ inch in height placed on the rails, over the joint-chair, and the shocks were borne without any injury to the joint. The bearing was originally 2 feet 6 inches long, but it was found, that the base of the chair might safely be reduced to 1 foot 9 inches, which had been done, without diminishing the steadiness of the chairs. The part of the line, on which they were used, was excellent, and the cost of maintenance of way was less than in other parts.

Mr. ALLPORT confirmed the evidence, as to the length, on which these joint-chairs were used, being the best part of the whole line, although it was subject to the action of the heavy engines and trains of the Great Northern Railway, passing over it at considerable speed.

Captain SIMMONS, R. E., being fully impressed with the importance of the subject, had listened with much attention to the discussion of a question which, however, he thought was of too great magnitude to be fully canvassed at a meeting of the Institution; he would, therefore, confine his observations to a very few points.

He had made some experiments on the permanent way described by Captain Moorsom, as at first he entertained some misgivings as to the solidity of the line, on account of the apparent weakness of the rails, the distance between the main chairs, and the absence of power in the intermediate saddle-pieces to afford lateral support to the rail; the experiment might, however, be considered generally satisfactory.

In considering the original construction of the railway, and the cost of maintenance of way, he thought that the amount of resistance to trains should be imported into the calculation. It had been stated in evidence, that at a speed of 60 miles per hour there was a resistance equal to about 60 lbs. per ton, on a narrow-gauge line, whilst, at the same speed, the resistance was reduced to 18 lbs. per ton, on a broad-gauge line. Now as there was not any very great difference in the form, arrangement, or weight of the locomotive engines on the two lines, he had been at a loss to account for the stated difference of resistance.

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He would now venture to suggest, whether the difference might not, to some extent, proceed from the different systems of forming the line; the longitudinal bearing affording that regular and continuous vertical and lateral support to the rail, which it only received at intervals from the cast-iron chairs on transverse sleepers; whilst, with the latter system, it was very difficult to prevent a certain amount of rocking motion in the chairs, which must produce considerable resistance; and at the joints, unless the rails were very heavy, or were 'fished,' the resistance was very much increased.

The system introduced by Mr. Fowler appeared to be a decided improvement; the joint-chairs were very steady, and the increased length, of 30 feet, given to the rails, was a very advantageous innovation, as it got rid of half the usual number of joints; provided, however, that the extra cost of such heavy lengths of rail did not militate against the introduction of the system.

Captain Simmons had examined the roads laid with Mr. W. H. Barlow's saddle-back rails; the line appeared to be good, and the construction solid; the principal objection against it seemed to be the anticipated heavy expense of renewal, when the upper table of the rails should be worn down, or the surface be laminated, or cracked. In conversation on the subject, with Mr. Morries Stirling, he had been informed, that it was practicable, at a slight expense, to impart a very durable surface to the rails, by the introduction of a mixture of metal during the process of rolling; that the compound metal, welded perfectly, and was as tenacious and much harder than the ordinary rails. If this process could be adopted, at a reasonable cost, it would prove a most advantageous adjunct in the use of Mr. Barlow's saddle-back rail.

The cast-iron bearer-plates, introduced by Mr. P. W. Barlow, had also received his attention; they appeared to have answered well, where they had been originally well packed and had been carefully attended to; but they were liable to fracture, if the substratum was not constantly kept well rammed beneath them: in short, like almost all other systems, if it was well attended to, it was durable, but, if not, the cast-iron way as soon got out of order as any other road.

Mr. Brunel was anxious not to be misunderstood in what he had stated, relative to the contraction and expansion of rails; he did not mean to imply, that iron rails were exempt from the ordinary effects due to changes of temperature; but that when rails were effectively held down to longitudinal, or other firm bearings, the effect of the amount of contraction, or expansion, occurring under the limited

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range of alterations of climate in Great Britain, would be resisted, and thus would not produce any of the effects of buckling upwards, or curving outwards, which would occur on lengths of rail inefficiently attached to the sleepers. He had tried lengths of several miles of rails firmly riveted together, and securely attached to longitudinal sleepers, without finding any ill effects from the contraction, or expansion.

He desired also to be understood, as to the opinion he expressed upon the numerous modifications of forms of rails exhibited in the diagrams, many, if not all of which, were made the subject of patents, although they had not been tried in any way, and most probably no person would ever attempt to try them; the only effect, therefore, to be anticipated from this accumulating of numerous fanciful forms in one patent was, that when a really good form was devised, it would be found to bear so close a resemblance to some one of these imagined sections, that either the use of the positive improvement would be prohibited, or a fertile field would be opened for litigation, on a case of infringement. For instance, some of the new forms shown, though in themselves impracticable, or objectionable, would have sufficed to prevent the use of Barlow's saddle-back rail, which though, perhaps, not positively new in form, must be admitted to be a decided improvement upon the rails of that description in ordinary use, and to be a good disposition of material; there was a good bearing, sufficient depth to give stiffness, and a breadth of base to insure firmness. Now the employment of this saddle-back rail, which was rather remarkable for its judicious proportions, and the good disposition of the metal, than for its novelty, might (as he before said) have been precluded by some such fanciful sections as those which had been theoretically advocated, although, he must say of them, that among them there was little that was new, and that little was not good. It was notorious, that engineers frequently found their practice restricted, by the claims of some theoretical patentee, whose obsolete invention never would have been heard of, but for the adaptation, in practice, of some, perhaps the only useful, portion of an invention, originally applied to some widely-different purpose. He feared that he should incur the ire of the inventive world but in these discussions he held it to be incumbent upon the Members; to give their unfettered opinions, however heretical they might be considered.

Reference had been made to the principle of having a false top to rails, to be removed when it became abraded, or laminated by the traffic. Now though this sounded well theoretically, it was generally considered to be useless in practice. Throwing aside the

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danger and other disadvantages, liable to result from the use of a rail composed of so many parts, as would be necessary for the removal and replacing of a false top, it would suffice to consider the monetary part of the question. If a rail weighing 90 lbs. per yard required to be changed, it was true that another rail of the same weight must be substituted, but the old metal could be re-rolled and converted into new rails at an expense of about two pounds per ton, which would probably be less than the cost of replacing the false tops in more complicated rails. It had been admitted, that the average duration of rails was ten years, and many engineers contended for a much longer duration; now a very simple calculation would suffice to demonstrate, that after ten years' use, it would be cheaper, and certainly much more economical in practice, to take up the entire rail, than to take to pieces and refix a complicated subrail, in order to replace the upper table. As a matter of figures, it must be evident, that at the present price of iron and with the actual facilities for rolling rails, no positive advantage could result from renewing the upper table of any form of compound rail yet proposed.

Mr. Brunel trusted that the remarks he had made would not be considered invidious: but he felt strongly the prejudicial effect of the present system of accumulating in one patent almost every possible modification of form, or process, and thus obstructing, if not frustrating, the attempts of others to introduce improvements which would become the unrestricted property of the public.

Mr. W. B. Adams, in answer to previous speakers, considered, that the amount of expansion and contraction must depend very much on locality and circumstances, as the iron might be laid where the heat would be carried off with such rapidity as not to affect the metal. It might, no doubt, be practicable to overpower a given force of expansion and contraction, by a greater force holding down the rails, but it then became a question whether it was desirable to do so, and whether the iron might not be injured, by the unnatural restriction to which it was subjected.

He could not comprehend, how the ballast remained firmly pressed upwards into the apex of the interior of the saddle-back rail, when the vibration occasioned by the travelling was considered, and he thought the deep cross-ties, necessary for preserving the inward level of the upper table, indicated a certain tendency to unsteadiness in that form, although its base was so widely spread.

With respect to the use of the fishing-pieces, he thought common sense must point out the advantage of giving to the joints, which were the weakest parts, such an amount of support, or stiffness, as would render them as steady as the intermediate parts, and in no

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manner could this be done so simply, or so effectually as by applying what might be termed 'splints,' to unite the two ends and impart to them as much strength as was possessed by the body of each rail, even if as much weight of metal was abstracted from the entire length as would supply the fishing-pieces; by this means the cost of fishing was much reduced. Experience had shown, that by the application of the system to old lines, the expense of relaying was avoided, and the increased comfort to the travellers, and the diminished wear and tear of the rolling stock were generally admitted.

The experiment tried by Mr. Hartley, had proved, that a certain elasticity of substratum was essential for a good permanent way.

He must submit, that the opinions, adverse to the forms of rails proposed in the paper, had been supported by assertion rather than by argument, or by the deductions of experience. If the various forms and arrangements were as defective as had been stated, they could not, by the simple fact of being included in a patent, become sufficiently important to interfere with the inventions, or improvements of engineers. The cast-iron subway, the saddle-back rail, the chilled chairs and wooden trenails, innumerable turn-tables and switches, and almost all the various parts composing a railway were already patented, so that, at all events, if there was any error in accumulating several forms in one specification, the sin had been committed, in emulation of very numerous, if not very good, precedents. The discussion of the question, whether patents should be permitted to be secured at all, belonged rather to another subject, and should not be imported into the present proceedings.

The moveable top for the rail, which had been so strongly objected to, had been proposed merely for certain localities, where the difficulties and cost of transport of rails of heavy weight would be considerable, when it should become necessary to replace the original rail. There were other forms, more analogous to the saddle-back rail, with which the latter might have been more correctly compared. There was a marked mechanical distinction between the saddle-back rail and the solid girder rail. In the specification of the former, it was described as "a trough rail bearing on the ballast and riveted to bearers," and the intention was, by widening a bridge rail to obtain a broader base. In the latter, the object was to obtain a T girder of such a depth as would prevent undue deflection, and with sufficient breadth to give ample bearing surface on the ballast, whilst the tread of the rail should be so slightly elevated, that there should be little, or no tendency to lateral yielding, or rocking.

In fact the saddle-back rail might be said to represent the shallow

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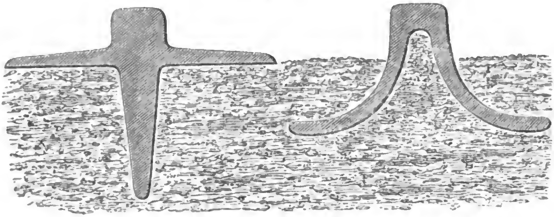
bridge rail of the longitudinal system, whilst the deep girder rail exemplified the T section of the transverse sleeper system.

A comparison of the actual proportions of the two forms would show (Fig. 25), that the girder rail possessed more bearing surface

Fig. 25.



Adams' Girder Rail. Barlow's Saddle-back Rail.

on the ballast, combined with a deep keel to prevent oscillation, and there was no greater difficulty in packing one form than the other, or rather, if there was any difference, it was in favour of the girder rail. As to the cost of manufacturing the deep girder rail, the same objections had been raised to the saddle-back form, but they had been overcome by the energy and skill of the iron manufacturers, and if there was a positive advantage in any given form of rails, means of producing them at moderate cost would soon be discovered. A crack, or flaw in the horizontal top of a "saddle-back" rail, would seriously injure it, but such a crack in a "girder-rail" would not impair its efficiency. The matter resolved itself into the question of which form, with a given weight of iron, offered the best bearing surface on the ballast, and possessed the greatest number of collateral advantages. Experience alone must decide; meanwhile Mr. Adams felt bound to endeavour to clear himself from the imputation of having proposed forms without ideas. The object of the paper was to direct attention to the T girder rail and its varieties;—to suggest the resumption of stone blocks, combined with either transverse, or longitudinal timber-sleepers; —the substitution of durable materials for the perishable ballast now in use;—giving to the rails a sufficient amount of elasticity to avoid the jarring which now acted so prejudicially on the rolling stock, and detracted from the comfort of the passengers; —and whilst providing for the drainage of the ballast, to afford the means of employing water, in dry seasons, for consolidating the packing, and laying the dust during the passage of the trains. In treating these various topics, the mention of the proposed methods

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for meeting certain difficulties, or for obtaining certain ends, was unavoidable, and experience had shown, that in bringing forward any new proposition, unless the first claim included every apparent mode of attaining the object, an unscrupulous improver, seizing upon the idea which had cost the inventor much thought, would, by a slight modification, obtain the credit and reap all the advantage of the invention.

When in 1847 Mr. Adams specified the "fish-joint," for the double-table rail supported on chairs, he thought that a good and valid title to an original idea had been recorded; but a host of followers in the same track immediately obtained patents for improvements, on the method of securing the joint of the double-table rail, used with chairs. This experience determined him, in future, to combine as many of these, so called, improved forms, or optional modes, as his imagination could supply, in order to avoid those disputes, which the protection of a successful invention was nearly certain to induce.

It was well known, that upon all lines of railway, there were used a multitude of patented inventions, and therefore, inventors might be permitted to hope, that even Mr. Brunel's antipathy to patented inventions would eventually be modified, and that the deep girder rail might be admitted for trial on the Great Western, or some other line of railway.

Mr. Errington said more reference should have been made to the use of stone blocks for railways, as, although they had been generally discarded in Great Britain, he thought there were many localities where stone might be used with advantage. It would be well to inquire into the causes of the block road being so completely abandoned. He had recently examined the Lancashire and Preston Railway, which had been open for twelve years, and in that period the blocks had only been replaced, to the extent of one-fiftieth of the whole.

The timber sleepers on the line had been replaced to the extent of one-half, though they were of excellent quality, and had been supplied at a time when there was no difficulty in getting larch timber. One-fortieth of the quantity of rails had been replaced, and it would now be requisite to replace one-twentieth more. The chief injury to the rails appeared to have arisen from the splitting at the joints, which clearly pointed out, that "fishing," or some other system, than had been hitherto pursued, was required. Whether, ultimately, there would not be a great deal of wear and tear, even with that new system, appeared doubtful, as the nuts, bolts and fishing-pieces would probably have to be replaced.

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With reference to the cost of maintenance of way, it was desirable to define what was meant by the term. In a document, published under the authority of the London and North Western Railway Company, it was stated, that the cost of the road, over an average of four hundred miles, had been hitherto £200 per mile per annum. Now it was impossible, that the small sums (£70 to £100) mentioned for maintenance of way, could comprise the same items as those in the document alluded to; he had known cases where, on one mile of railroad, there had been deposited 2,000 cubic yards of ballast, in one year. The upholding, referred to in the London and North-Western Railway Report, included the maintenance of every great work on the line—bridges, tunnels, slips, drains, and ballast, in fact, everything an engineer could desire to have done, in order to preserve a perfect plane for the rolling stock, and that condition was generally rigidly enforced. In some cases it was not usual, in maintaining a road, to replace a key, or spike, or rail, the moment it was wanted, and to include it in the maintenance, but it was reserved for a future time, when the cost was included in that of more special restoration out of the capital. He thought, on the present occasion, although the object was, perhaps, rather to discuss the mechanical merit of certain forms of construction, yet in so purely commercial a matter as a railway, the vital question of cost should not be lost sight of. It was yet to be proved, whether the saddle-back rail could be maintained at anything like the expense that had been stated; but he could not believe, that in the price named, anything approaching to a general maintenance of way had been included. It was therefore desirable to obtain further information on that point.

Mr. P. W. Barlow stated, that the cost of maintenance given by his brother at £42 per mile, included the upholding of the fences, ballasting, and the ordinary repairs of the road; any extraordinary expenses, such as the giving way of tunnels, or other large works, or large slips, were not included. Everything was comprehended that would be comprised in a contract for maintenance. Mr. Wythes, the Contractor for maintaining the way with cast-iron bearings, had informed him, that when the road was consolidated, one man per mile would be sufficient to keep it in repair, and in that he included the ordinary cost of fences and of maintaining the road.

Mr. Bidder said much valuable time had been wasted in the discussion of the speculative portions of the paper, which he thought was not quite of the character pointed out in the list of subjects circulated among the members of the Institution. No more important subject could be treated of, than the construction and

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maintenance of permanent way; a paper on such a subject ought to enter fully into detail, and the first thing to be clearly ascertained was, what was meant by the term "maintenance of way," which was stated to have cost all sorts of sums, varying between £42 and £200 per mile. Descriptions of the mode of laying transverse, or longitudinal sleepers were not required, but a paper on this important subject, should have traced the results of all the experiments upon, and trials of, the various systems which had been tried. Now the paper under consideration chiefly contained observations on a great many forms of rails, but did not attempt to supply information on the methods of doing the best work in the most economical manner, whether in the construction of a new line, or in repairing an old one.

Allusion had been made to the rail first laid on the Blackwall Railway; it had bevelled joints, which were described as being weak; now in fact the joint was not weakened, as it was made by twisting the web of the rail and cutting off a portion of the protuberant end. The rail was certainly rendered somewhat more expensive, by the introduction of a process, which he would recommend on every railway, namely, by causing the iron to undergo additional hammering in the course of the manufacture; that had only cost thirty shillings per ton, and he believed the extremely durability of the old rails was, to some extent, owing to the extra-manufacturing process to which the iron was submitted. If instead of introducing large and heavy rails, a more perfect mode of manufacture had been sought for, he thought they would have had more economical railways.

The great question (although he admitted they were scarcely in a condition to settle it) was, which was the best system of construction to be adopted, at the present time, for a new line of railway; they would have to choose between the longitudinal system (which was, perhaps, brought to the greatest perfection by Mr. Brunel),—the transverse system,—and the saddle-back rail. There remained then to be considered, the prices of wood and of iron, the relative durability of all the materials employed, and their value when renewed. If the price of wrought-iron was assumed to be £5 10*s*., and cast-iron £4 per ton, and sleepers 4*s*. each, it was practicable to use heavy rails, and cast-iron bearings, if otherwise deemed advantageous; but if iron rose to £12 per ton, it would be necessary to use more timber.

He had been in the habit of assuming the durability of a good rail to be fifteen years; that an ordinary unprepared sleeper would last six years, and a creosoted sleeper fifteen years: then arose the question of the value of the old materials, and, at the present

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prices, he thought those of the longitudinal system were of the least value, next came the transverse system, and the most valuable were those of the saddle-back rail system. Therefore, in England, he should be inclined to adopt the latter; at the same time, in Norway, it had been found more expedient to adopt the longitudinal system, because sleepers cost there only about sixpence each, and for that locality, which offered several peculiarities, it was considered the safest kind of road; and he begged to acknowledge the handsome manner in which Mr. Brunel had supplied him with all the information he required.

Then came the question of the best mode of repairing an existing road; and, from observation and careful inquiry, he had arrived at the conclusion, that the fish-joint was the most effectual system. He was of opinion, that the simple packing of the road could be done, as had been stated, for £40 per mile; but on the question of maintenance of way, generally, the Institution required to be furnished with a considerable amount of data, before the subject could be satisfactorily discussed; and he trusted some Member would supply a comprehensive paper on the subject, in the course of the next Session.

Mr. G. H. Phipps said, the statement, of there being, practically, no prejudicial effect from riveting together long lengths of rails, had excited considerable surprise; but, from his own observation, he was prepared to admit the fact of there being no perceptible effect of contraction, or expansion, if the rails were firmly fastened down upon longitudinal bearings; he thought this was as demonstrable by theory as it appeared to be positive in practice.

Mr. Hawkshaw regretted there had not been more precision in the terms of the discussion. It was just as practicable to define the duration of a rail, as that of a grindstone; it must be evident, that it was dependent on certain considerations; a rail might last any term, between five years and twenty years. The fact was, the life of a rail was in proportion to the number, velocity, and weight of the trains running over the line. He had some rails, weighing 42 lbs. per yard, on the Preston and Wyre Railway, which had been laid twelve, or thirteen years, and now appeared capable of serving for ten years more, whilst, on other lines, he had renewed heavier rails, which had only been laid from three to nine years. When, therefore, the duration of permanent way was mentioned, the nature and amount of the traffic should be specified, or otherwise the conclusions arrived at would be erroneous. The cost of maintenance of permanent way had been referred to, without any statement of the weight and number of the trains, of the expense of the

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ballast, of the cost of the iron, or of the precise character of the works.

It was important, also, to consider which system of permanent way offered the least resistance to the passage of trains. He was aware of the difficulty of treating the subject; but it was evident, that a railway might be cheaply laid, and yet, by increased deflection, might offer great resistance, and if it thus augmented the cost of power, there was not much gained by the innovation. A few years ago he had been obliged to take up a piece of railway, which offered less resistance to trains than any line he had yet seen; it was laid by Mr. Hartley, who had attempted to make a line like a lathe bed; the construction was very rigid, the rails were rubbed by hand, into blocks of stone, until a perfectly smooth surface was obtained, and while the line was in working order, it offered only small resistance; but when, partly from its inherent rigidity, it once got out of order, there was no remedy but to take it up and to put down what must be considered to be an inferior road, but which was better adapted to the nature of the traffic.

Captain Simmons, R. E., said, that even if, in addition to the gross cost of maintenance of way, the separate expense of each kind of material was given, with all the details that had been mentioned, and all necessary allowances were made, it would still be nearly impossible to arrive at an accurate comparison of the cost of any two lines, on account of the difference in the rolling stock. The weight on the driving-wheels of the engines varied with every class, and the hammering effect of certain kinds of locomotives, must have a very serious effect on the permanent way.

Mr. Brassey, in answer to the President, said his experience did not enable him to accord with the statement, that a line could be maintained in effective working condition for £30, or £40 per mile. He admitted that his practice in the maintenance of railways, though extensive, had been confined to lines laid on transverse sleepers, generally with rails of 75 lbs. per yard, chairs of 25 lbs. each, and with iron spikes, and he must state, that he had not been able to find any road which had been more economically maintained, yet he could not have it well done for less than £80 or £90 per mile, and he believed he had not done worse than other contractors, nor had he many idle men in his employ. If he had to construct a railway and to keep it in repair for twenty years, he should use rails of 75 lbs. per yard, on transverse timber sleepers, with 25 lbs. chairs, fastened down with iron spikes, as being less liable to rot than wooden trenails.

Mr. Bethell, through the Secretary, begged to correct what he

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contended was an erroneous statement relative to the inflammability of creosoted timber. During its very extensive use, for upwards of fifteen years, there was only one instance of a structure suffering from fire; and that one was a bridge in Wales, which had been set on fire by a workman driving a red-hot bolt into a creosoted beam.

When Mr. Bethell's premises, at Battersea, were burned down in 1847, the stacks of unprepared timber caught fire long before that which had been creosoted. He conceived the reason for this, to be, that unprepared timber, when heated, gave off a vapour which caught fire at a lower temperature than that at which the vapour from creosoted timber would inflame, because creosote oil required a high temperature to volatilize it. Therefore he contended, that creosoted timber would not catch fire so soon as unprepared wood; but he admitted that when once it was on fire it burned for a longer time.

There was not any instance on record of any of the stacks of creosoted sleepers catching fire, although they were generally placed close beside the railways, and were constantly exposed to the falling upon them of red-hot cinders and sparks from the locomotive engines.

With respect to the duration of prepared sleepers, it was now an accepted fact, that if carefully creosoted, they would endure for at least twenty years; and as regarded the price, the general estimate of 5*s*. per intermediate sleeper, and of 10*s*. per joint sleeper, had proved to be rather over than under the actual contract prices.

Mr. R. Stephenson, V.P., said the subject under discussion had occupied his attention for many years, and he had some time ago arrived at the conclusion, that the maintenance of permanent way was, as nearly as possible, an insoluble problem, unless by first carefully analyzing every element by which it was influenced; and even then, as those elements were inconstant, and as no two cases could be found exactly parallel, it was evident, that no correct comparison of cost could be arrived at. He quite agreed, that if the traffic was small and the speed slow, stone blocks sufficed for a railway for the conveyance of heavy minerals, at a speed of about ten, or twelve miles per hour, indeed he thought that a stone-block road offered less resistance than a timber-sleeper line.

With these slow trains resistance was a very important object, because by its diminution, an engine of a given power, was enabled to drag after it ten tons, or twenty tons, in addition to the ordinary load; but when it was necessary to convert the power of the engine into velocity, the case was entirely changed, and then that kind of permanent way, best adapted to resist repeated shocks, with the least

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injury to the rolling stock, became necessary, and under these circumstances the stone blocks made the worst road.

Even if it was admitted, for the sake of argument, that there was a little more resistance with one system than with the other, it became of little importance, as at high velocities the question of atmospheric resistance came into consideration, and that was entirely apart from the present question. He could not suppose the remarks had intended to imply, that any ordinary difference in the construction of a line could cause any material difference in the resistance of trains. At the time of the discussion on that subject, a wide difference of opinion was entertained by men of experience, but that had nothing to do with the present question. Therefore the distinction he drew was, that on a mineral road, with moderate speeds, stone blocks could be safely applied; but with the high speeds required by passenger traffic, they were quite out of the question; he conceived that his position was proved by the result of the experiment tried by Mr. Hartley, who in constructing a very rigid unyielding line, as nearly as possible resembling a lathe bed, had only produced a perfect block road, which was soon proved to be unfitted for traffic at a great velocity. The cost of maintenance of way must depend, in a great degree, upon the nature of the strata, and the character of the country, through which the line passed; one cutting would keep the men continually employed in repairs, whilst in another cutting, the grass would grow even beneath the rails; the former being in a wet clay, with sand, and the latter in a dry, firm, sandy soil, without any water near it. The simple introduction of a little water, which would be found to vary in all localities, made all the difference; so that if the costs of maintenance of each railway were separately analyzed, it would be found, that instead of being able to compare one line with another of the same length, it would scarcely be possible to compare two miles of the same line. It was therefore a problem, which, at present, could not be solved. He did not wish to be understood as decrying the value of a record of actual facts; on the contrary, it would be highly useful, as if all the circumstances and considerations were clearly stated, an approximate judgment might be formed. But it required great care in ascertaining whether the cases, to which the facts were applied, involved the same facts to the same extent. The question was one of great importance to the railway world, and he hoped the Institution would continue to receive, from resident engineers on railways, the results of the cost of maintaining permanent way, and that the papers would clearly define what was comprehended under the head of maintenance.

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It was imperative to arrest the impression, which was entertained by some persons, that it was desirable to obtain a perfectly rigid road; Mr. Stephenson's experience had led to exactly the opposite conclusion. It was quite true, that a rigid road might, theoretically speaking, be considered the best, but in practice it was the worst, for although from its rigidity it might offer the least resistance, it increased the wear and tear prodigiously. His attention had been called, some years ago, to the fact of the rails in the Watford Heath cutting, on the London and North Western Railway, being split and crushed, to such an extent, that although the cutting was through gravel, the rails were removed two, or three times. On a personal examination of the spot, he soon perceived that the destruction of the iron, arose entirely from the gravel having been extremely well consolidated, and the stone blocks so firmly bedded and packed, that the line was rigidly unyielding, and consequently the iron rails were literally crushed under the fast traffic.

The chief causes of deterioration of the permanent way, were the mileage, the speed, and the weight of the trains passing over the line; though the weight *per se* of the engines and its distribution upon the wheels, must also be considered. Wear and tear was, then, entirely a question of certain weights passing along the rails, at given speed; in a given time; the destruction of the surface being accelerated nearly as the speed, and the general dilapidation being augmented in an increasing ratio, as the number and the weight of the trains were increased beyond a given point.

Mr. Stephenson trusted, that the question of 'permanent way' was only opened by the present paper, as it was one of vital importance and could not be too frequently brought before the Institution of Civil Engineers.

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